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Trace Metal Assessment in a Water Hyacinth (*Eichhornia crassipes*)-Infested Reservoir: A Study of Awba Reservoir, Ibadan, Nigeria

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ABSTRACT

Analysis of some trace metals (cadmium, Cd; chromium, Cr; lead, Pb; manganese, Mn; zinc, Zn) in reservoir water, reservoir sediment, and water hyacinth (*Eichhornia crassipes*) organs (roots and leaves) were carried out at four locations to assess their heavy metal status and the phytoremediation potential of water hyacinth for the removal of trace metal contaminants. The order of overall mean concentrations of trace metals in the reservoir is Mn > Pb > Cr > Cd = Zn. The location with dense mats of water hyacinth recorded significantly lower ($P < 0.001$) mean water and sediment Mn values compared to the plant organs. The bioconcentration factor for leaves was in the order of Mn > Zn > Pb > Cd > Cr while that for roots was Mn > Cr > Zn > Cd > Pb. Only Mn, from among all trace metals studied, was substantially bioaccumulated in the organs of water hyacinth. The maximum bioconcentration factor values for leaves (97.98) and roots (644.80) for Mn suggests that water hyacinth could be regarded as a moderate bioaccumulator of Mn in the reservoir. However, results show that the other trace elements have the potential to be bioaccumulated at lower concentrations in water. Zn recorded the lowest mean root/leaf translocation ratio while Mn recorded the highest. This study shows that water hyacinth has a high tolerance for Mn in the reservoir.

Keywords: aquatic plants, atomic absorption spectroscopy, bioaccumulation, phytoremediation, translocation ratio

INTRODUCTION

Water hyacinth (*Eichhornia crassipes*) is one of the worst weeds in aquatic or terrestrial environments (Holm *et al.* 1977). It is recognized as a very aggressive species of aquatic plant, which grows very fast and eliminates other aquatic species in its competition (Dixit and Tiwari 2007). Makhanu (1997) reported a doubling time of 5-15 days; however, according to Nyananyo *et al.* (2007), the plant has a doubling time of 6-8 days and a leaf turn-over rate of 60-70% per month. This perennial herb, which was first reported in Nigeria in 1983 (Makhanu 1997) but is native to Brazil (Dixit and Tiwari 2007), is associated with environmental hazards such as degraded water quality and drastic changes in plant and animal communities; light and oxygen diffusion are severely curtailed by this floating plant. Other hazards include clogging of irrigation, hydropower and water supply ways, hindrance of water transport, blockage of canals and rivers causing flooding (Nyananyo *et al.* 2007).

Aneke *et al.* (2007) studied the physicochemical properties of chloroform extract of water hyacinth leaves. Uka and Ukachukwu (2007) reported dense mats of this invasive aquatic weed in Awba Reservoir. The authors compared water hyacinth-infested and open areas of the reservoir using physico-chemical characteristics during the rainy season and recorded significantly higher mean values of conductivity, total suspended solids, free carbon dioxide and turbidity in water hyacinth-infested areas compared to open waters. However, the water hyacinth-infested area recorded significant lower values of dissolved oxygen, pH and nitrate nitrogen. The authors concluded that the low level of nitrate nitrogen in water hyacinth-infested areas compared to open waters was due to its utilization by water hyacinth. This is in agreement with Nyananyo *et al.* (2007) on River Num because nitrate is an essential plant nutrient. Ukiwe *et al.* (2007) reported an increased rate of potassium ion uptake by water hyacinth resulting from an upsurge in nutrient levels as a result of increased agricultural, industrial and human waste activities around the lower reaches of the Niger River. The quest for nutrients by water hyacinth can be directed into a more useful purpose. Ukiwe *et al.* (2008a) reported the highest adsorptive property (58% decolourisation) and highest ash content impurities (3.53 mg/l) of the activated carbon of water hyacinth compared to two other plants (*Chloraphora excelsa* and *Gmelina arborea*).

Water hyacinth has the tendency of accumulating heavy metals such as cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn) into its root tissues from polluted water (Nyananyo *et al.* 2007). Ukiwe *et al.* (2008b) showed that sorption of some heavy metals such as chromium (Cr) and Cu by water hyacinth was highest at a pH of 6.0 compared to a more acidic pH of 2.0. However accumulation of Pb, nickel (Ni) and Cd was independent of water pH levels. Heavy metals, unlike organic substances, cannot be biodegraded but have the ability to bioaccumulate in the environment and biomagnify through the food chain (Harun *et al.* 2008). Heavy metal pollution, therefore, affects the biota and may consequently have harmful effects on humans. Increasing awareness of the harmful impacts of heavy metal pollution has triggered the interest of various scientists on ways to reduce the harmful impacts of these trace metals on the environment.

Investigators into the phytoremediation potential of water hyacinth include Johnson and Sheehan (1977) in laboratory cultures; Win *et al.* (2003) from industrial wastewaters; Liao and Chang (2004) from constructed wetlands; Lu *et al.* (2004) and Keith *et al.* (2006) in outdoor experi-

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ments; Dixit and Tiwari (2007) from polluted waters; and Harun *et al.* (2008) from natural habitats. Johnson and Sheehan (1977) reported that Fe, Zn and especially Mn were held in the root systems of water hyacinth and also transported to leaf tissues in laboratory cultures. Liao and Chang (2004) reported the ability of water hyacinth to absorb trace elements (Pb, Cd and Zn) more easily from water than from sediments. Lu *et al.* (2004) showed that the phytoaccumulation of Cd and Zn had an effect on the relative growth of water hyacinth and that the accumulation of these trace elements in shoots and roots increased with initial concentration of trace elements and with the passage of time. Keith *et al.* (2006) showed that water hyacinth was not suitable for the phytoremediation of arsenic and Cu but was a hyper accumulator of Cr. Dixit and Tiwari (2007) opined that the distribution of heavy metals in the plant body depends on the availability and concentration of heavy metals as well as individual plant species and its density.

This study assesses the level of some trace elements in sediment, water and organs (roots and leaves) of water hyacinth (*Eichorrnia crassipes*) in Awba reservoir. We also determine its phytoremediation potential for these trace elements.

MATERIALS AND METHODS

Study area

The Awba Reservoir is located at the south-western end of the University of Ibadan. It lies between latitude 3° 53′ E and 7° 26′ N and at an altitude of 185 m above sea level (Akin-Oriola 2003). The reservoir has a surface area of 6 ha. According to Ugwumba (1990), the reservoir is 8.3 m high, 110 m long with a crest of 12.2 m high. It has a maximum depth of 5.5 m and a maximum length of 700 m. It can hold 230 million liters of water (Omotosho 1981). It was constructed in 1964 by draining the Awba stream and impounding the water at a point where it flows through a natural valley. It was constructed for the dual purpose of water supply and table fish production for the University community. It has all along been a centre of scientific research within and outside the University.

Methodology

Four sampling locations in the reservoir were selected for sample collection. Location 1 is the entry point for this study and receives sewage and domestic effluents from the residential student halls and the zoological garden. Location 2 is a discharge area for chemical effluents from the surrounding science laboratories. It was therefore taken as the possible polluting site of the Awba Reservoir. Location 3 is the area around the spillway of the lake. By the time of sampling this area was covered with thick mats of *E. crassipes* compared with other locations. Location 4 is the area from which water is abstracted for domestic supply, including drinking. It is supposed to be a relatively less polluted site and so was used as a kind of control site.

Samples were collected in March 2009. Samples for water quality studies were collected in plastic bottles that had been previously soaked in 10% nitric acid for 48 hrs, and rinsed with distilled water. The container was rinsed three times on site with reservoir water before collecting the water sample for metal analysis. All samples were filtered with cellulose acetate filters and acidified to pH 2 with acid before transporting to the laboratory. All samples for metal analysis were stored in the refrigerator at about 4°C to inactivate the bacteria and prevent change in volume due to evaporation. Water samples were digested using nitric acid. The representative samples of bulk sediment were collected using a clean stainless steel trowel from 5-15 cm depth, then thoroughly mixed and stored in labeled polythene bags for laboratory analysis. Sediment samples were air-dried for about 5 days; ground using a silica pestle and mortar and sieved through a 2-mm mesh sieve. Sediment samples were digested in Teflon beakers with a mixture of HNO_3, HCl and HF. Samples of the water hyacinth (*E. crassipes*) were randomly hand picked, packed into clean plastic bags that were previously soaked in dilute nitric acid and thoroughly washed with distilled water. In the laboratory, plant samples were then separated into leaves and roots and dried for 12 hrs at 120°C in an oven. The dried plant samples were ground using an electronic blender and stored in clean plastic bottles. Similarly, plant samples (leaves and roots) were digested with a mixture of 1 ml 60% $HClO_4$, concentrated 5 ml HNO_3 and 0.5 ml H_2SO_4. Appropriate blanks were prepared to check for background contaminants by the reagents used.

The digested samples were analyzed for trace elements using an atomic absorption spectrophotometer, Alpha Star model 4 (Chem Tech Analytical) available at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria.

Data analysis

Bioconcentration factor (BF) was calculated as the concentration in tissue divided by concentration in water (Lu *et al.* 2004). BF provides an index of the ability of a plant to accumulate metal with respect to the concentration of the metal in the substrate. Translocation was calculated by dividing the amount of trace metal in root by the amount of trace metal in leaf. A large value of translocation ability implies a poorer translocation capability. GenStat (2008) 7th Edn (Discovery Edn 3) v. 7.2.2.222, VSN Intl. Ltd. was used to carry out a two-way analysis of variance for location and sample.

RESULTS

Trace metal concentration

The mean Mn values followed a similar pattern for all locations with water < sediment < leaves < roots (**Table 1**). Mn values ranged from 0.01-8.67 ppm with a mean value of 2.27 ± 0.45 ppm. The mean Mn values for location showed significant difference ($P < 0.05$), with Location 3 recording a significantly lower value (2.05 ± 0.85 ppm) compared with other locations. Mean Mn values also showed significant differences for samples ($P < 0.001$) (**Table 2**), with roots (7.57 ± 0.18 ppm) and leaves (1.25 ± 0.08 ppm) recor-

Table 1 Heavy metal concentration (Mean ± standard error) and range in parts per million (ppm) for four locations of Awba Reservoir. Mean values are from values of sediment, water, root and leaf.

Location	Heavy metal concentration[a] (Mean ± standard error)				
	Mn	Cr	Pb	Zn	Cd
1	2.37 ± 1.01 a	0.04 ± 0.01 a	0.05 ± 0.01 a	0.03 ± 0.01 a	0.04 ± 0.01 a
2	2.36 ± 0.94 a	0.07 ± 0.02 a	0.07 ± 0.02 a	0.04 ± 0.01 a	0.04 ± 0.01 a
3	2.05 ± 0.85 a	0.04 ± 0.01 a	0.14 ± 0.07 a	0.04 ± 0.01 a	0.04 ± 0.01 a
4	2.31 ± 0.94 a	0.03 ± 0.01 a	0.05 ± 0.01 a	0.05 ± 0.01 a	0.03 ± 0.01 a
Total	2.27 ± 0.45	0.04 ± 0.01	0.08 ± 0.02	0.04 ± 0.00	0.04 ± 0.00
Range	0.01 - 8.67	0.00 - 0.18	0.00 - 0.91	0.00 - 0.10	0.00 - 0.14
P value	0.99	0.14	0.28	0.67	0.61
LSD value	2.67	0.03	0.10	0.02	0.02
CV (%)	142.9	91.7	159.7	68.8	72.3

[a]**;** Heavy metal concentration in parts per million (ppm).

One-way Analysis of Variance using least significant difference (LSD) method is adopted to determine difference among mean values for each trace metal.

Means with different alphabets for each column (heavy metal) are significantly different ($P < 0.05$) from each other.

Table 2 Heavy metal concentration (Mean ± standard error) in parts per million (ppm) for four samples of Awba Reservoir. Mean values are from values of the four sampling locations chosen for this study.

Sample	**Heavy metal concentration**^{a} **(Mean ± standard error)**				
	Mn	**Cr**	**Pb**	**Zn**	**Cd**
Water	0.04 ± 0.01 a	0.04 ± 0.01 a	0.15 ± 0.07 a	0.03 ± 0.01 a	0.02 ± 0.00 a
Sediment	0.22 ± 0.03 a	0.06 ± 0.02 a	0.06 ± 0.01 a	0.05 ± 0.01 b	0.04 ± 0.01 a
Root	7.57 ± 0.18 c	0.05 ± 0.01 a	0.06 ± 0.01 a	0.03 ± 0.01 a	0.04 ± 0.01 a
Leaf	1.25 ± 0.08 b	0.03 ± 0.01 a	0.05 ± 0.01 a	0.04 ± 0.01 ab	0.05 ± 0.01 a
P value	< 0.01	0.44	0.19	0.05	0.16
LSD value	0.28	0.03	0.10	0.02	0.02
CV (%)	14.9	94.5	158.1	64.2	69.7

**a; ** Heavy metal concentration in parts per million (ppm).
One-way Analysis of Variance using least significant difference (LSD) method is adopted to determine difference among mean values for each trace metal.
Means with different alphabets for each column (heavy metal) are significantly different ($P < 0.05$) from each other.

Table 3 Bioconcenteration Factor (Mean ± standard error) of trace metals in leaf of water hyacinth for the sampling stations of Awba Reservoir.

Location	**Bioconcenteration Factor**^{a} **(Mean ± standard error)**				
	Mn	**Cr**	**Pb**	**Zn**	**Cd**
1	36.95 ± 6.85	1.27 ± 0.71	0.94 ± 0.51	1.01 ± 0.41	1.67 ± 0.48
2	49.0 ± 25.3	0.65 ± 0.26	0.82 ± 0.22	1.11 ± 0.74	2.61 ± 1.11
3	22.27 ± 1.40	1.89 ± 1.08	0.92 ± 0.50	17.88 ± 12.51	3.05 ± 0.28
4	61.2 ± 22.8	1.35 ± 1.16	0.37 ± 0.10	1.85 ± 0.32	1.72 ± 1.13
Total	42.35 ± 8.59	1.29 ± 0.40	0.76 ± 0.17	5.46 ± 3.44	2.26 ± 0.40
Range	13.91 - 97.98	0.04 - 4.05	0.02 - 1.79	0.14 - 42.36	0.49 - 4.44
P Value	0.47	0.80	0.68	0.24	0.60
LSD value	56.66	2.86	1.22	20.45	2.74
CV(%)	71.1	117.9	84.5	198.9	64.3

a; One-way Analysis of Variance shows that means for each column (heavy metal) are not significantly different ($P > 0.05$) from each other.

Table 4 Bioconcenteration Factor (Mean ± standard error) of trace metals in root of water hyacinth for the sampling stations of Awba Reservoir.

Location	**Bioconcenteration Factor**^{a} **(Mean ± standard error)**				
	Mn	**Cr**	**Pb**	**Zn**	**Cd**
1	230.70 ± 32.20	1.28 ± 1.01	0.59 ± 0.17	0.40 ± 0.20	1.37 ± 0.94
2	276.10 ± 155.10	0.49 ± 0.18	0.79 ± 0.16	0.38 ± 0.11	1.57 ± 0.74
3	158.50 ± 20.60	8.02 ± 5.53	0.69 ± 0.34	9.08 ± 6.79	3.87 ± 2.05
4	383.50 ± 159.90	4.58 ± 3.01	0.68 ± 0.36	1.60 ± 0.64	2.49 ± 1.55
Total	262.20 ± 54.10	3.59 ± 1.63	0.69 ± 0.12	2.87 ± 1.82	2.39 ± 0.67
Range	84.43 - 644.80	0.09 - 18.97	0.03 - 1.28	0.01 - 22.64	0.16 - 7.25
P value	0.58	0.38	0.97	0.29	0.61
LSD value	368.5	10.39	0.89	11.12	4.62
CV(%)	74.6	153.6	68.1	206.2	105.5

a; One-way Analysis of Variance shows that means for each column (heavy metal) are not significantly different ($P > 0.05$) from each other.

ding significantly higher values compared with sediment (0.22 ± 0.03 ppm) and water (0.04 ± 0.01 ppm) values. Cr values ranged from 0.00-0.19 ppm with a mean value of 0.04 ± 0.01 ppm. There was no significant difference ($P < 0.05$) in the mean values for location and sample. Location 2 recorded the highest Cr value (0.07 ± 0.02 ppm) while Location 4 recorded the lowest (0.03 ± 0.01). For sample, sediment recorded the highest Cr value (0.06 ± 0.02 ppm) while leaves showed the lowest (0.03 ± 0.01 ppm). Pb values ranged from 0.00-0.91 ppm with a mean value of 0.08 ± 0.02 ppm. All values recorded were lower than 0.1 ppm except for the water sample (0.14 ± 0.07 ppm) from Location 3 (0.15 ± 0.07 ppm). There was, however, no significant difference ($P > 0.05$) in location and sample. Zn values ranged from 0.00-0.10 ppm with a mean of 0.04 ± 0.00 ppm. There was no significant difference ($P > 0.05$) in mean values for location while sample means showed a significant difference ($P < 0.05$). The mean sediment value (0.05 ± 0.01 ppm) recorded was significantly higher than that of roots (0.03 ± 0.01 ppm) and water (0.03 ± 0.01 ppm). Cd values ranged from 0.00-0.14 ppm with a mean of 0.04 ± 0.00 ppm. There was no significant difference ($P > 0.05$) in mean values for location and sample.

BF

Mn recorded the highest mean BF (42.35 ± 8.59) in the leaves of water hyacinth (**Table 3**), followed in descending order by Zn (5.46 ± 3.44), Cd (2.26 ± 0.40), Cr (1.29 ± 0.40) and Pb (0.76 ± 0.17). Mn and Zn recorded maximum BF values of 97.98 and 42.36 for the leaves of water hyacinth while the other trace metals recorded BFs < 10. For the roots of water hyacinth (**Table 4**), Mn recorded the highest mean BF (262.20 ± 54.10), followed in descending order by Cr (3.59 ± 1.63), Zn (2.87 ± 1.82), Cd (2.39 ± 0.67) and Pb (0.69 ± 0.12). Mn recorded the highest BF value (644.80), followed by Zn (22.64) and Cr (18.97). Cd and Pb each recorded BF < 10.

The relationship between trace metal concentration in water with that in the root and leaf of water hyacinth followed a similar pattern for all trace metals. **Figs. 1** and **2** show that at lower concentrations of trace metals in water, higher BFs were recorded and this follows a log-linear relationship.

Translocation ratio

The lowest mean root-leaf translocation ratio (**Table 5**) was recorded by Zn (0.86 ± 0.03), followed by Cd (1.04 ± 0.26), while Mn recorded the highest (6.30 ± 0.47). The lowest translocation ratio was recorded by Zn (0.05) and Cd (0.05), while Cr recorded the highest value (27.22).

DISCUSSION

The overall mean concentrations of trace metals in order is Mn > Pb > Cr > Cd = Zn. Pb, Cr and Cd did not show significant difference for location and sample; as a result, water hyacinth can not be regarded as having the potential to accumulate these trace metals in the reservoir. However,

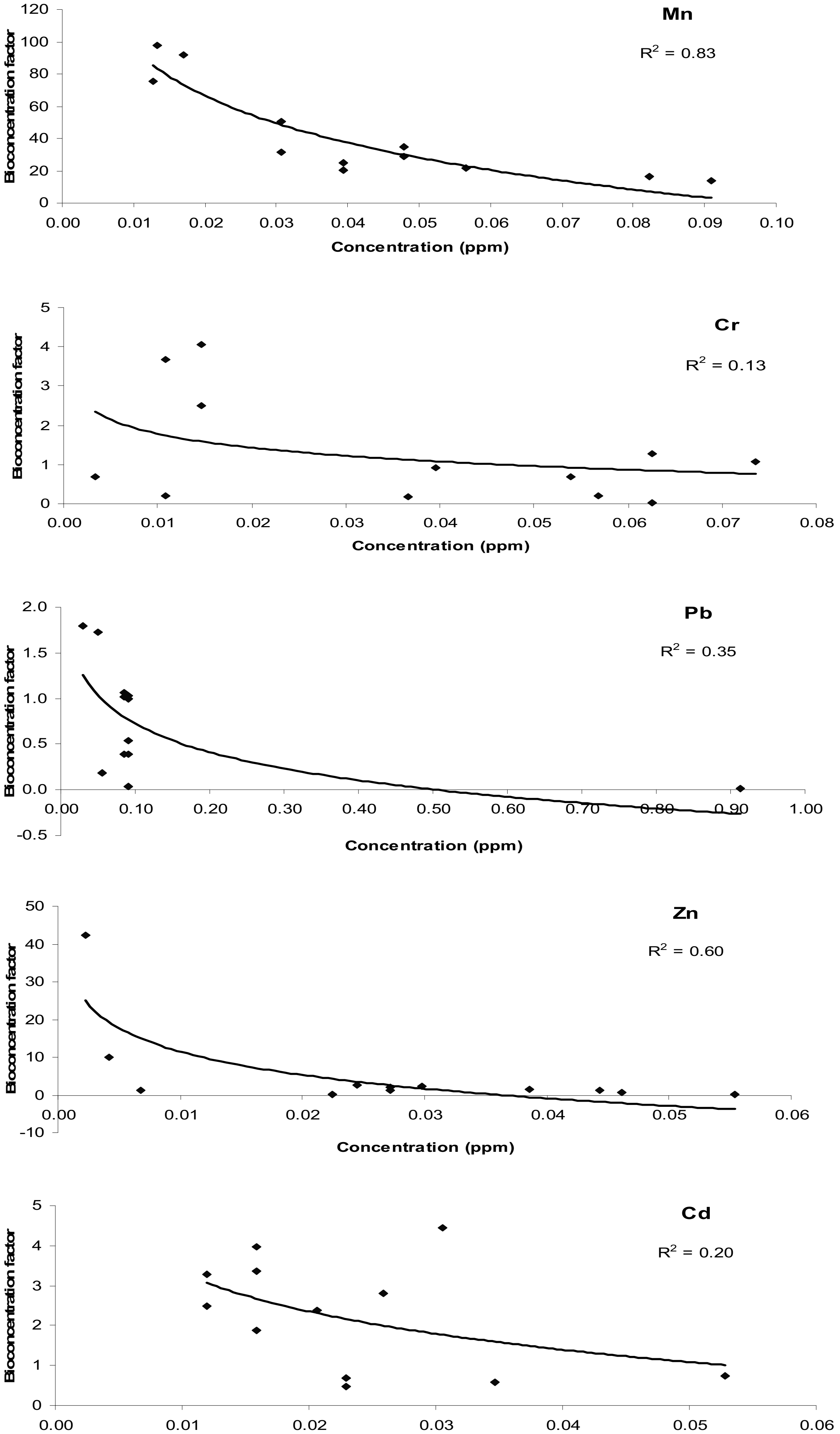

Fig. 1 Relationship between trace metal concentration in water and bioconcentration factor in leaf of water hyacinth from Awba Reservoir.

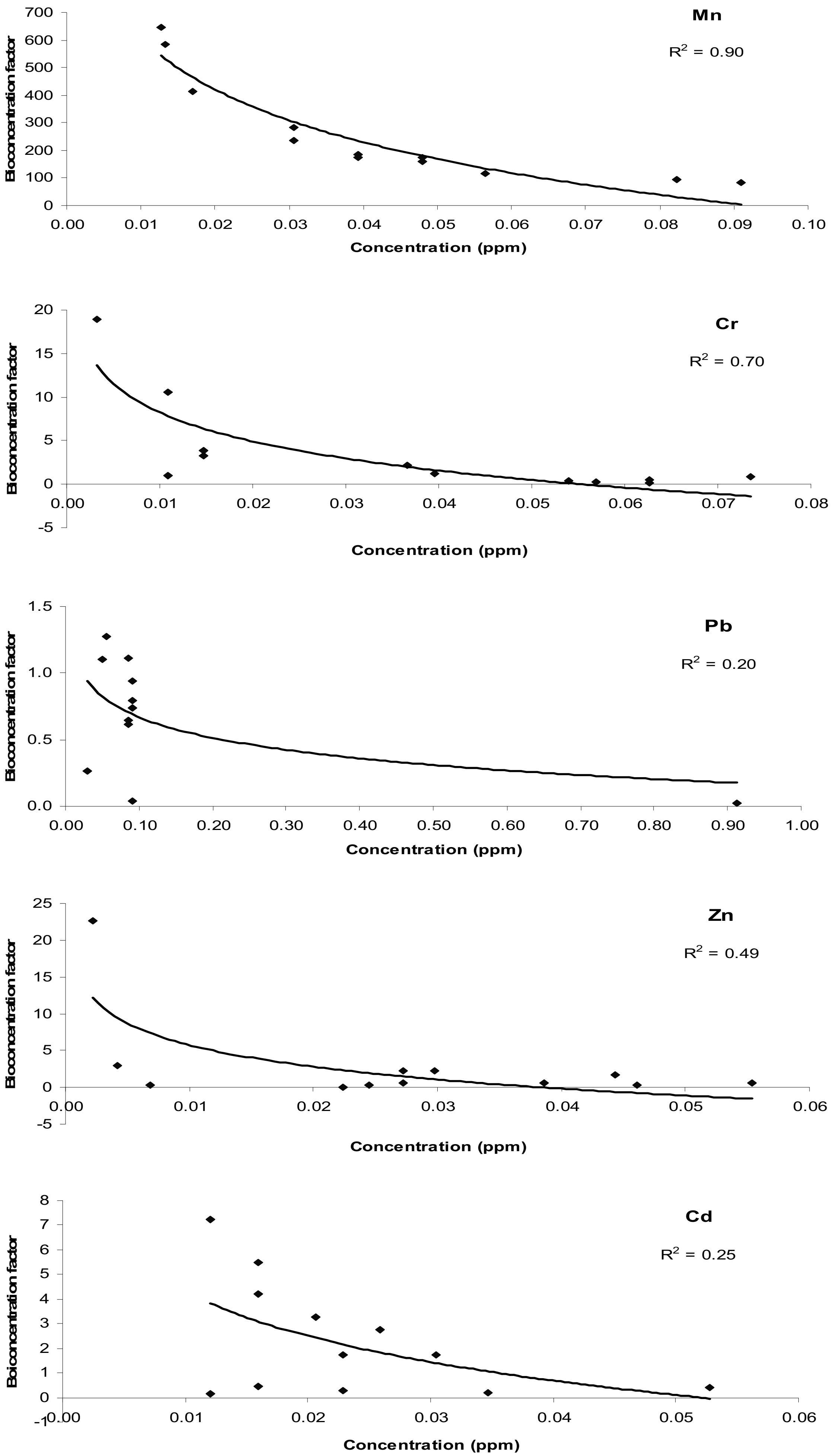

Fig. 2 Relationship between trace metal concentration in water and bioconcentration factor in root of water hyacinth from Awba Reservoir.

Table 5 Mean (± standard error) and range of translocation (root/leaf) ratio of trace elements in water hyacinth for Awba Reservoir.

	Trace metals				
	Mn	**Cr**	**Pb**	**Zn**	**Cd**
Mean[a]	6.36 ± 0.47	4.75 ± 2.27	3.07 ± 1.68	0.86 ± 0.33	1.04 ± 0.26
Range	4.51 – 8.94	0.35 – 27.22	0.07 – 20.60	0.05 – 4.21	0.05 – 2.90

[a]: Mean (± standard error)

the ability of water hyacinth to absorb these trace metals have been reported (Win *et al.* 2003; Liao and Chang 2004; Lu *et al.* 2004; Dixit and Tiwari 2007). Mn recorded the highest mean concentration values of all the trace metals; the root recorded the highest mean value for all locations, followed in order by the leaf, sediment and water. The mean root value of Mn was significantly higher than that of the leaf and both were significantly higher than those of water and sediment. This shows that water hyacinth has a high tolerance for Mn in the reservoir, and can therefore, be regarded as a good candidate for phytoremediation of Mn in the reservoir. The significant lower mean Mn values recorded at Location 3, where thick mats of water hyacinth were observed, suggests that the plant substantially accumulates Mn from water. The mean sediment value for Zn was significantly higher than those of water and root, suggesting that water hyacinth is not a good bioaccumulator of Zn in the reservoir. Harun *et al.* (2008) reported higher values of Zn in the roots of water hyacinth compared to their stalk and leaves. Lu *et al.* (2004) also recorded a maximum value of 9652.1 ppm for Zn in the root of water hyacinth.

The bioaccumulation factor for leaf was in the order of Mn > Zn > Pb > Cd > Cr while that for root was in the order of Mn > Cr > Zn > Cd > Pb. Dixit and Tiwari (2007) reported that Pb, Zn and Mn tend to show greater affinity towards bioaccumulation. For all trace metals in the reservoir, there is the tendency that they can bioaccumulate at lower concentrations. Therefore the inability of water hyacinth to bioaccumulate Cd, Pb, Cr and Zn appreciably may be due to the high concentration of these trace metals in the reservoir. A high bioaccumulation of trace elements by water hyacinth in water environments with low concentrations of some trace elements have also been reported (Liao and Chang 2004; Keith *et al.* 2006), although Johnson and Sheehan (1977) reported that higher Mn and Zn concentration in laboratory solution cultures increased their foliar and root levels. However, Win *et al.* (2003) concluded that Pb accumulated mainly in the roots of water hyacinth at low concentrations and in the petiole at higher concentrations and duration. The maximum BF values for leaf (97.98) and root (644.80) were recorded for Mn in the reservoir. Lu *et al.* (2004) reported a maximum BF of 622.3 and 788.9 for Cd and Zn, respectively and regarded water hyacinth as a moderate accumulator of both trace elements. Therefore, water hyacinth could be regarded as a moderate bioaccumulator of Mn in the reservoir. Antagonism between trace metals may also be responsible for the lower concentration of other trace metals compared with Mn in the tissue organs of water hyacinth. (Johnson and Sheehan 1977) reported antagonism in laboratory cultures with Fe decreasing with higher Mn levels. Cd recorded a higher BF than Zn for both leaves and roots; however, Lu *et al.* (2004) reported a higher BF for Zn than for Cd at the same duration. Zn is an essential micronutrient for plant metabolism and growth (Harun *et al.* 2008), can easily be taken up in roots, and becomes extremely toxic when present in excess. However, Cd is one of the most toxic heavy metals and is considered non-essential for living organisms (Lu *et al.* 2004).

The translocation of the root/leaf ratio was in the order of Mn > Cr > Pb > Cd > Zn. This is in agreement with results obtained by Liao and Chang (2004) who recorded a translocation of the root/shoot ratio in the order of Cu > Pb > Cd > Ni > Zn. The mean root/leaf translocation ratio recorded for Zn is < 1. This suggests that the trace metal is sequestered more into the leaves from the roots, and shows that it is involved more in the metabolic processes of the leaf, being an essential micronutrient. However, the high ratio recorded for Mn suggests that it is not taken up easily by the leaves of water hyacinth from the roots.

This study shows that water hyacinth has a high tolerance for Mn in the reservoir, and is the only trace metal with substantial bioaccumulation in the organs of water hyacinth. However, results show that the other trace elements have the potential to bioaccumulate at lower concentrations of the elements in water. Zn recorded the lowest mean root/leaf translocation ratio suggesting that it bioaccumulates more in the leaf compared to the root tissues.

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