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Cu, Ni and Zn Phytoremediation and Translocation by Water Hyacinth Plant at Different Aquatic Environments.

Doaa M. Hammad.

Doaa Mohamed Hammad, Researcher, Central Laboratory for Environmental Quality Monitoring (CLEQM), National Water Research Center (NWRC), Barrage, El-kanater, Qalubiya, Cairo, Egypt.

Abstract: The ability of water hyacinth (*Eichhornia crassipes* (Mart.) Solms.) to absorb and translocate copper (Cu), nickel (Ni) and zinc (Zn) was studied at three different aquatic environments (River Nile, agricultural drain & mixed industrial and agricultural drain). Results showed that at all the studied locations, Cu, Ni and Zn were more accumulated in water hyacinth roots; their concentrations in the roots were 2 to17 times higher than in the shoots. Trace metals accumulation in root tissues was found to be in the order of Zn > Cu > Ni. Maximum values of bioconcentration factor (BCF) for Cu, Ni and Zn in water hyacinth roots were 1344.6, 1250.0 and 22758.6 respectively, indicating that the accumulation potential of Zn by water hyacinth is higher than that for Cu and Ni. Translocation ability (TA) is the ratio between the concentration of a trace element accumulated in root tissues by that accumulated in shoot tissues; a larger ratio implies poorer translocation capability. In this study the ratio results were in the order of Ni > Cu > Zn revealing that Zn is more mobile from roots to shoots than Cu & Ni. Highest concentrations of Cu, Ni and Zn in water were recorded at the mixed industrial and agricultural drain; this was accompanied by the highest accumulation of the three metals in roots of water hyacinths collected from this drain, suggesting that metal content of water hyacinth roots can serve as good bioindicator of metal pollutaion at different aquatic environments. Based on BCF values of the three metals in plant roots, water hyacinth can be primarily utilized as a good phytoaccumulator of Zn followed by Cu then by Ni. Statistical analysis showed positive significant correlations between the trace metals concentrations in ambient water and their accumulation and bioconcentration in roots and shoots of water hyacinth plant.

Key words: Water hyacinth, Phytoremediation, Trace metals (Cu, Ni & Zn), Bioconcentration factor, Translocation ability, Bivariate analysis.

INTRODUCTION

Toxic heavy metal pollution of water and soil is a major environmental problem, and most conventional remediation approaches do not provide acceptable solutions (Lu, *et al*., 2004). Recently there is a considerable interest in developing cost effective and environmentally friendly technologies for the remediation of soil and wastewater polluted with toxic trace elements (Zayed, *et al*., 1998). The value of metal-accumulating plants to wetland remediation has been recently realized (Black, 1995). This capability is useful in removing toxic heavy metals and trace elements from contaminated soils and waters in a process referred to as phytoremediation (Weiliao and Chang, 2004). Phytoremediation is the process of using plants to extract, sequester, and/or detoxify pollutants (Meagher, 2000). One application of phytoremediation technology is rhizofiltration; which is primarily used to remediate extracted groundwater, surface water, and wastewater with low contaminant concentrations (Ensley, 2000). It is defined as the use of plants, both terrestrial and aquatic, to absorb, concentrate, and precipitate contaminants from polluted aqueous sources in their roots. Rhizofiltration can be used for Pb, Cd, Cu, Ni, Zn, and Cr, which are primarily retained within the roots (United States Protection Agency, 2000).

Copper (Cu) is an essential micronutrient for plants, but it can be toxic at higher concentrations. Cu contributes to several physiological processes in plants including photosynthesis, respiration, carbohydrate distribution, nitrogen and cell wall metabolism, seed production including also disease resistance (Kabata-Pendias and Pendias, 2001). The higher concentration of Cu may account for the suppressed root growth, leaf chlorosis observed among plants (Baker and Walker, 1989). On the other hand, Khan and Moheman (2006) reported that nickel (Ni) is considered to be among non essential elements needed for the healthy growth of plants, animals and soil microbes. However, recent literature survey suggests that nickel is an essential element in many species of plants and animals. It interacts with iron found in haemoglobin and helps in oxygen transport, stimulate the metabolism as well as being regarded as a key metal in several plants and animals enzyme systems, however at higher concentrations Ni can be toxic (Jadia and Fulekar, 2009). Zinc (Zn) is considered as an essential and beneficial element for human bodies and plants. Complete exclusion of Zn is not possible due to its dual role, an essential microelement on the one hand and a toxic environmental factor on the

Corresponding Author: Doaa M. Hammad, Doaa Mohamed Hammad, Researcher, Central Laboratory for Environmental Quality Monitoring (CLEQM), National Water Research Center (NWRC), Barrage, El-kanater, Qalubiya, Cairo, Egypt.
E-mail: drdoaahammad@yahoo.com

other (Brune, *et al*., 1994). However, Zn can cause nonfatal fume fever, pneumonitis, and is a potential hazard as an environmental pollutant (Hampp, *et al*., 1976).

Water hyacinth (*Eichhornia crassipes* (Mart.) Solms.) is one of the great members of aquatic plant species successfully used for wastewater treatment (Narain, *et al*., 2011). It is a vascular fast growing floating aquatic plant which is commonly found in tropical and subtropical regions of the world with a well developed fibrous root system and large biomass. It can adapt easily to various aquatic conditions and plays an important role in extracting and accumulating metals from water. Hence, it is considered to be an ideal candidate for use in the rhizofiltration of toxic trace elements from a variety of water bodies (Weiliao and Chang, 2004). The objectives of this study were: (a) To evaluate the efficiency of water hyacinth plant in accumulating the trace metals Cu, Ni and Zn from different aquatic environments. (b) To determine the bioconcentration factors (BCF) of these metals in plant roots and shoots (c) To examine the capability of water hyacinth plant in translocating these metals (TA).

MATERIALS AND METHODS

Description of the Study Area:

water and plant samples were collected in duplicates from El-Ghamaza el kobra drain (agricultural drain) located at 885 Km from High Aswan Dam, on the right bank of the River Nile, its average discharge into River Nile is of 0.05 million m^3/day, EL-Tibeen drain (mixed drain from industrial wastes and agricultural runoff) located at 898.1 Km from High Aswan Dam on the right bank of the River Nile, surrounded by huge industrial factories such as iron and steel factory, it takes its water from El-Khashab Canal and its average discharge into River Nile is of 0.02 million m^3/day. Both drains located at Helwan governorate. Water and plant samples were also collected from right and left banks of River Nile at El-Akhsas area downstream El-Ghamaza el kobra drain and at Shoubra area far downstream El-Tibeen drain. River Nile samples were taken for comparison and to monitor the impact of the two drains under investigation on the downstream of River Nile. The study area extended for about 48 Km as shown in Figure (1). Codes of sampling locations and their description were represented in Table (1). Abbreviations used in Tables (3-5) & Figures (2-8) and their interpretation were illustrated in Table (2).

Table 1: Codes of Sampling Locations.

Code	Description	Type of samples
G	El Ghamaza el kobra drain	Water & plant samples
T	El-Tibeen drain	Water & plant samples
N1	River Nile, right bank, downstream El Ghamaza el kobra drain (El-Akhsas area)	Water samples
N2	River Nile, left bank, downstream El Ghamaza el kobra drain (El-Akhsas area)	Water & plant samples
N3	River Nile, right bank, far downstream El Tibeen drain (Shoubra area)	Water & plant samples
N4	River Nile, left bank, far downstream El Tibeen drain (Shoubra area)	Water & plant samples

Hint: No water hyacinth plants found at N1 sampling location.

Table 2: Abbreviations Used in Tables 3-5 & Figures 2-8.

Abbreviations	Interpretation of Abbreviations
Cu-w	Cu concentration in water, mg/l
Cu-r	Cu accumulation in plant roots, mg/kg dry wt.
Cu-s	Cu accumulation in plant shoots, mg/kg dry wt.
BCF Cu-r	Bioconcentration factor of copper in plant roots, dimensionless
BCF Cu-s	Bioconcentration factor of copper in plant shoots, dimensionless

Note: The other trace elements' definitions were the same as Cu.

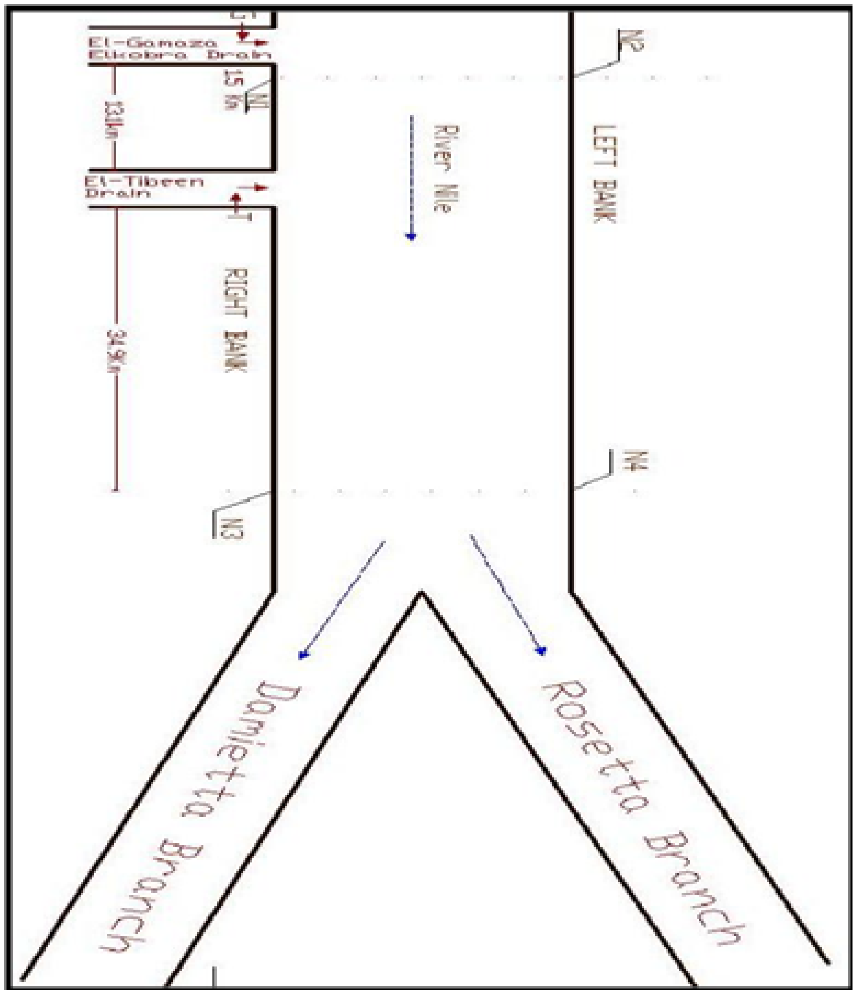

Fig. 1: Schematic Diagram Illustrating Sampling Locations.

Water and Plant Sampling:

Water sampling was carried out according to standard methods for examination of water and wastewater (APHA, 2005). Surface water samples were collected in polyethylene containers of two liter capacity, and then acidified to pH 2 with nitric acid to prevent microbial reactions. Enough individual water hyacinth plants were collected at each sampling station to overcome the factor of plant variability (Chapman and Pratt, 1961). In the laboratory, the plants were carefully washed with distilled water then divided into roots and shoots, Oven dried in a dust-free, forced draft electrical oven at $65^{o}C$ for about 48 hours to stop enzymatic reactions, removing moisture and to obtain a constant weight, then ground to a fine powder before analysis.

Analytical Methods:

Chemical analyses were carried out according to standard methods for examination of water and wastewater (APHA, 2005). Water samples were filtered through Whatman GF/C filters before analysis. The concentrations of Cu, Ni and Zn were determined by using the Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) with Ultra Sonic Nebulizer (USN). 0.5 gram from each powdered plant sample was weighed and treated with a mixture of the digestion reagents $H_2SO_4/HClO_4$ as reported by Tolg (1974) for destruction of organic matter in plant tissues during which temperature was raised to about $100^{o}C$ until the digest became clear. After dilution to 25 ml deionized water the digest was filtered through Whatman GF/C filters and analyzed for total Cu, Ni and Zn using the ICP-OES instrument.

Bioconcentration Factor and Translocation Ability:

The bioconcentration factor (BCF) provides an index of the ability of the plant to accumulate the metal with respect to the metal concentration in the substrate. It is calculated as the ratio of the trace element concentration in the plant tissues at harvest to the concentration of the element in the external environment and is dimensionless (Zayed, *et al*., 1998).

BCF is given by: BCF = (P/E) $_i$***:***

Where i denotes the heavy metal, P represents the trace element concentration in plant tissues (mg/kg dry wt.) and E represents the trace element concentration in the water (mg/l). A larger ratio implies better phytoaccumulation capability.

Translocation ability (TA) was calculated by dividing the concentration of a trace element accumulated in the root tissues by that accumulated in shoot tissues and is dimensionless (Wu and Sun, 1998).

TA is given by: TA = (Ar/As) $_i$***:***

i denotes the heavy metal, Ar represents the amount of trace element accumulated in the roots (mg/kg dry wt.) and As represents the amount of trace element accumulated in the shoots (mg/kg dry wt.). A larger ratio implies poorer translocation capability.

Statistical Analysis:

Concentrations of trace metals in water and in plant tissues along with the calculated bioconcentration factors (BCF) were subjected to Bivariate statistics: correlation (bivariate) by using SPSS statistical program (Levesque, 2007).

RESLUTS AND DISCUSSION

Cu, Ni and Zn Levels in Ambient Water :

Data represented in Table (3) and illustrated by Figure (2) showed that Cu concentrations at all the studied locations were higher than those recorded for both Ni and Zn at the same locations. Cu levels ranged between 0.013 & 0.13 mg/l, Ni between 0.008 & 0.012 mg/l while Zn values varied between 0.003 & 0.029 mg/l. The highest concentrations of Cu, Ni and Zn were detected in water samples collected from El-Tibeen drain. Generally, Cu, Ni and Zn values recorded at all the sites under investigation were below the standard limits of the Egyptian Environmental Law 9/2009 which stated a value not exceeding 0.1 mg/l for Ni and a value not exceeding 1.0 mg/l for both Cu and Zn in River Nile, its branches and treated industrial effluets. Similar results obtained by Abd El-Hady (2007) who recorded traces of Zn, Cu, Ni, Pb and Cd, in water samples collected from Nile water and El-Khashab Canal, fluctuating between 0.01 and 0.05 mg/l.

Table 3: Cu, Ni and Zn Concentrations (mg/l) in Water Samples Collected from Different Sites under Investigation.

Location	Cu-w	Ni-w	Zn-w
G	0.03	0.01	0.011
N1	0.024	0.009	0.005
N2	0.038	0.01	0.003
T	0.13	0.012	0.029
N3	0.058	0.01	0.007
N4	0.013	0.008	0.004

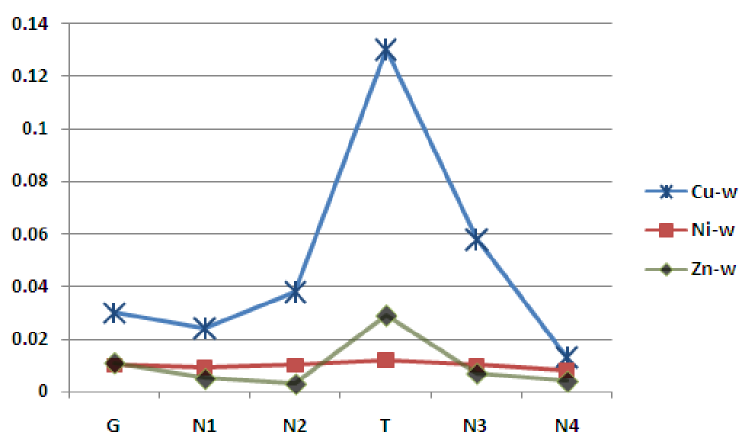

Fig. 2: Cu, Ni and Zn Concentrations (mg/l) in Water Samples of the Studied Locations.

Cu, Ni and Zn Accumulation by Water Hyacinth Plant:

In the present study, at all the studied locations, water hyacinth accumulated higher concentrations of Cu, Ni and Zn in the roots (Table 4 & Figures 3, 4 & 5). Highest accumulation in root tissues (from 24.75 to 660.0 mg/kg dry wt.) was recorded for Zn, while Cu accumulation was in the range of 18.75 & 115.0 mg/kg dry wt. On the other side the least accumulation of 5.65 to 16.0 mg/kg dry wt. was observed for Ni; these values showed that the affinity of water hyacinth in accumulating Zn is higher than that for Cu and Ni.

In shoot tissues, at all the studied locations, also Zn recorded the highest level of accumulation (9.26 - 112.5 mg/kg dry wt.) followed by Cu (2.5 – 19.0 mg/kg dry wt.) then by Ni (0.5 – 2.2 mg/kg dry wt.); this demonstrated that Zn is more mobile from roots to shoots than Cu and Ni.

Lu, *et al*. (2004) reported that the accumulation of metals in the roots and shoots of water hyacinth has been shown in many field studies in which water hyacinth was used as a biological monitor for metal pollution (Zaranyika and Ndapwadza, 1995). Stratford, *et al*. (1984) found that the metals' accumulations in water hyacinth increased linearly with the solution concentration in the order of leaves < stems < roots. The present study demonstrated a pattern of metal uptake similar to that of Stratford, *et al*. (1984) where Cu, Ni and Zn were tended to be accumulated more in roots than in shoots at all the sites under investigation. Soltan and Rashed (2003) treated water hyacinth with several heavy metals (Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn) and concluded that water hyacinth accumulated higher concentrations of heavy metals in the roots than in the aerial parts.

Table 4: Cu, Ni and Zn Concentrations (mg/kg dry wt.) in Roots & Shoots of Water Hyacinth Plant and their Bioconcentration Factors.

Location	**Cu-r**	**Cu-s**	**BCF Cu-r**	**BCF Cu-s**
G	18.75	2.5	625.0	83.3
N2	22.06	7.35	580.5	193.4
T	115.0	19.0	884.6	146.2
N3	22.1	7.4	381.0	127.6
N4	17.48	6.2	1344.6	476.9
Location	**Ni-r**	**Ni-s**	**BCF Ni-r**	**BCF Ni-s**
G	8.55	0.5	855.0	50.0
N2	10.85	2.2	1085.0	220.0
T	16.0	1.65	1250.0	137.5
N3	9.2	1.4	920.0	140.0
N4	5.65	1.15	706.25	143.75
Location	**Zn-r**	**Zn-s**	**BCF Zn-r**	**BCF Zn-s**
G	40.95	17.76	3722.7	1614.5
N2	27.05	9.26	9016.7	3086.6
T	660.0	112.5	22758.6	3879.3
N3	36.25	20.53	5178.6	2932.9
N4	24.75	11.27	6187.5	2817.5

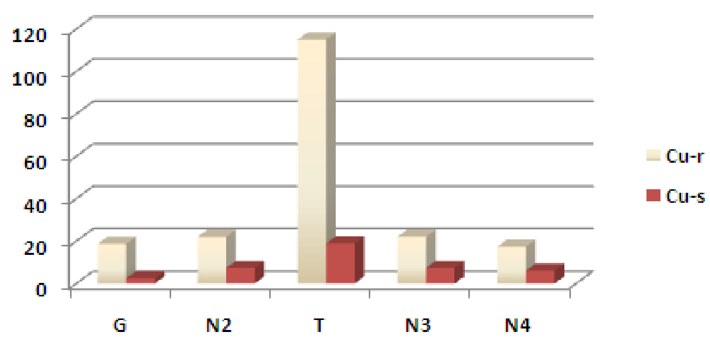

Fig. 3: Cu Concentrations in Plant Tissues (mg/kg dry wt.).

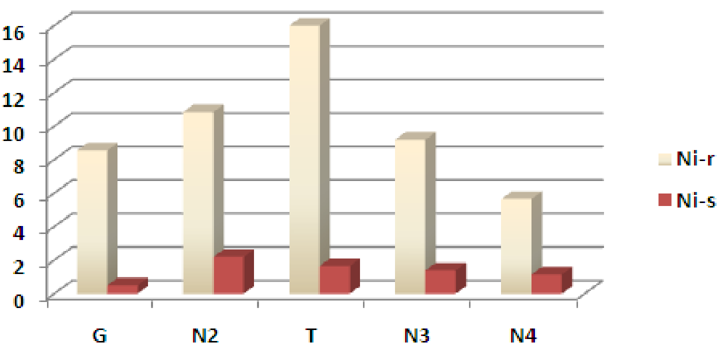

Fig. 4: Ni Concentrations in Plant Tissues (mg/kg dry wt.).

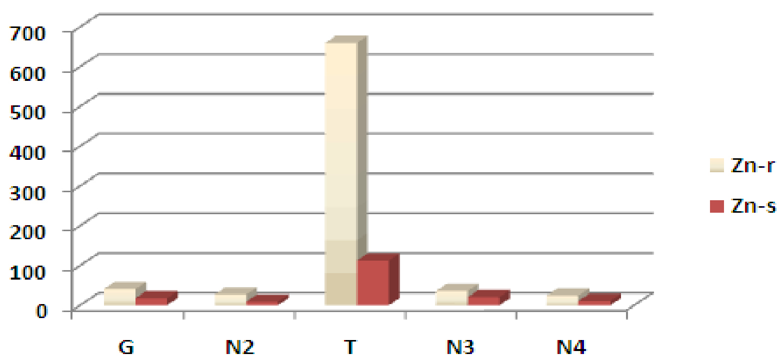

Fig. 5: Zn Concentrations in Plant Tissues (mg/kg dry wt.).

Robb and Pierpoint (1983) mentioned that certain elements such as Pb, Ni, Cu, Zn, Fe, Cr, Mn and V being preferentially retained by the root system. Lyngby and Brix (1982) and Jana (1988) proved that macrophyte roots accumulate larger concentrations of Cr, Cu, Fe, Ni, Pb, and Zn than other plant organs. Yahya (1990) reported that a greater proportion of metals absorbed remained in the root system rather than being translocated to other plant parts. Again, Abd- Elhamid, (1996) found that the roots of aquatic plants accumulated heavy metals to a much greater extent than the stems and leaves. Zhu, *et al*. (1999) examined the potential of water hyacinth for the phytoremediation of six trace elements [As (V), Cd (II), Cr (VI), Cu (II), Ni (II) and Se (VI)] in natural and constructed wetlands, they indicated that Cd, Cr, Cu, Ni, and As were more highly accumulated in roots than in shoots. In contrast, Se was accumulated more in shoots than in roots at most external concentrations.

Zhu, *et al*. (1999) also reported that the main route of heavy metal uptake in wetland plants was through the roots in case of emergent and surface-floating plants like water hyacinth and that much of the accumulation into the plant tissue is by adsorption to the anionic sites in the cell walls and the metals do not enter the living plant. This explains why wetland plants can have very high magnitude of heavy metal concentration in their tissues compared to their surrounding environment.

On the other hand Vesk, *et al*. (1999) found that Cu, Zn & Pb were not localized at the root surface. In contrast with iron, their levels increased centripetally across the root, tended to be higher inside cells and were highest within cells in the stele. Additionally Deng, *et al*. (2004) mentioned that metals accumulated by wetland plants were mostly distributed in root tissues, suggesting that an exclusion strategy for metal tolerance widely exists in them. On the other side some species/populations could accumulate relatively high metal concentrations (far above the toxic concentration to plants) in their shoots indicates that internal detoxification metal tolerance mechanism(s) are also included.

Generally, water hyacinth rhizomes and roots could help in the removal of heavy metals from the aquatic habitats or constructed wetlands. Therefore, it is undesirable to involve contaminated rhizomes and roots in fodder or co-compost organic fertilizer. The contaminated water hyacinth may be dry ashed and heavy metals could be extracted and recycled (Abdel-sabour, 2010).

According to Bowen (1979) typical concentrations in plant tissues should not exceed a range of 5-20 mg/kg dry wt. for Cu and a range of 0.02-5 mg/kg dry wt. for Ni, while for Zn Chapman and Pratt (1961) stated a normal range of 5-75 mg/kg dry wt. Roots of water hyacinth plants especially those collected from El-Tibeen drain were found to accumulate higher concentrations of Cu, Ni and Zn that were exceeding the ranges recorded above, indicating that El-Tibeen drain environment is more contaminated by these metals. This was emphasized by the water analysis of El-Tibeen drain (Table 3) which recorded the highest levels of the three metals under investigation. These results suggest that metal content of water hyacinth roots can serve as good bioindicator of metal pollutaion at different aquatic environments.

Bioconcentration Factor:

According to Zhu, *et al*. (1999) and Abd-Elmoniem (2003), the ratio between plant metal concentration and that of the growth media expresses the bioconcentration factor (BCF) which reflects the affinity of aquatic macrophytes to a specific heavy element or pollutant. Lu, *et al*. (2004) mentioned that metal accumulations by macrophytes can be affected by metal concentrations in water and sediments (Lin and Zhang, 1990). The ambient metal concentration in water was the major factor influencing the metal uptake efficiency (Rai and Chandra, 1992). In general, when the metal concentration in water increases, the amount of metal accumulation in plant increases, whereas the BCF values decrease (Wang and Lewis, 1997).

In the present study, mostly the BCF values of Cu, Ni & Zn increase when their concentrations in ambient water decreased (Tables 3 & 4). Zhu, *et al*. (1999) demonstrated that water hyacinth had high trace element bioconcentration factors when supplied with low external concentrations of all six elements [As (V), Cd (II), Cr (VI), Cu (II), Ni (II) and Se (VI)]. Carvalho and Martin (2001) found that Cd, Cu, Ni, Pb, and Zn were associated with large BCF at low concentrations. Soltan and Rashed (2003) recorded that water hyacinth effectively removed appreciable quantity of heavy metals (Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn) from freshwater especially at low concentrations. Lu, *et al*. (2004) found that the BCF values of Zn in water hyacinth roots and shoots decreased when the ambient water concentration of Zn increased. Weiliao and Chang (2004) determined that when the external environment had a low concentration of Cu level at 0.18 mg/l, the BCF of roots was highest at 6,166. Rugigana (2007) mentioned that high metal concentration is toxic to the growth of water hyacinth plant therefore the bioaccumulation factor will increase with a low metal concentration and decrease with the increasing of the metal concentration.

In the present study ambient water concentrations of Zn at all the studied locations were lower than those for Cu & Ni (Table 3); this was accompanied by the highest BCF values for Zn in water hyacinth roots & shoots. Maximum BCF values for Cu, Ni and Zn in water hyacinth roots were 1344.6, 1250.0 and 22758.6 respectively; while their maximum BCF values in shoots were 476.9, 220.0 and 3879.3 respectively (Table 4 & Figures 6 & 7). Zhu, *et al*. (1999) stated that a good accumulator is recognized by two criteria in experimental conditions (a) its ability to take up concentration more than 5,000 mg /kg dry wt. of a given element, and (b) its ability to bioconcentrate the element in its tissues; for example, the BCF value exceeds 1,000.

In this study, water hyacinth did not absorb Cu, Ni or Zn in concentrations greater than 5,000 mg /kg dry wt. Therefore, only the BCF in plant roots & shoots was considered to evaluate the effectiveness of water hyacinth as a phytoremediator for these metals. The roots met the criteria for Cu at N4 sampling location where the least concentration of Cu (0.013 mg/l) in ambient water was recorded. The BCF of Ni in roots exceeds 1,000 at N2 & T sampling locations. Shoots of water hyacinth did not meet the criteria for both Cu & Ni at any of the sampling locations. On the other side roots and shoots of the plant met the criteria for Zn at all the sites under investigation, revealing that the efficiency of water hyacinth plant in accumulating Zn is higher than that for Cu and Ni. Based on the BCF values of the three metals in plant roots, water hyacinth can be primarily used as a good phytoaccumulator of Zn followed by Cu then by Ni.

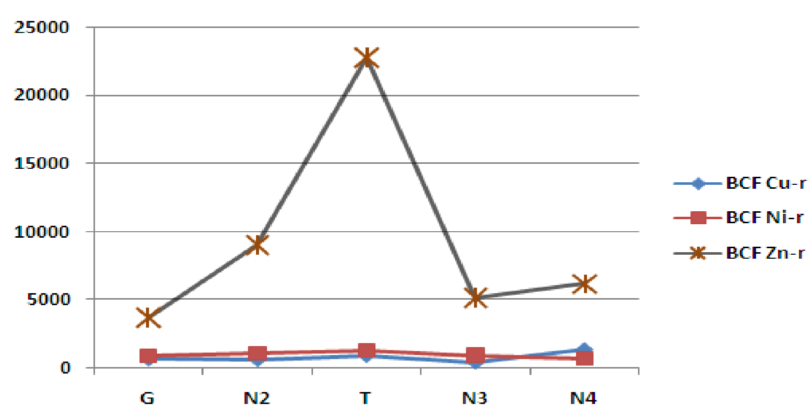

Fig. 6: BCF Values of Cu, Ni and Zn in Water Hyacinth Roots .

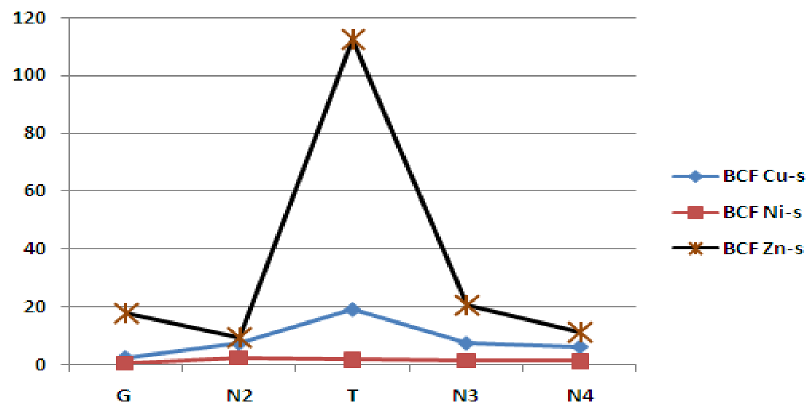

Fig. 7: BCF Values of Cu, Ni and Zn in Water Hyacinth Shoots.

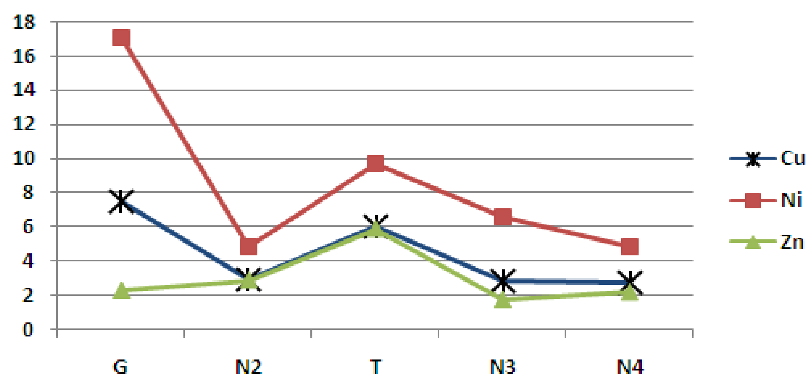

Fig. 8: Translocation Ability (root/shoot ratio) of Water Hyacinth with Respect to Cu, Ni & Zn.

Translocation Ability:

The movement of metal-containing sap from the root to the shoot, termed translocation, is primarily controlled by two processes: root pressure and leaf transpiration (Lasat, 2000). Some metals are accumulated in roots, probably due to some physiological barriers against metal transport to the aerial parts, while others are easily transported in plants (Lu, *et al*., 2004). In the present study Cu concentrations in roots were about 3 to 7.5 times higher than in shoots, while Ni concentrations were about 5 to 17 times higher in roots than in shoots, on the other hand Zn concentrations in the roots were about 2 to 6 times higher than that in the shoots. Similar results obtained by Weiliao and Chang (2004) who found that water hyacinth roots accumulated about 3 to 15 times more Cd, Pb, Cu, Zn, and Ni than did the shoots.

(Lu, *et al*., 2004) mentioned that Normally Zn, Cd or Ni concentrations are 10 or more times higher in root than in shoot (Chaney *et al*., 1997). Qian, *et al*. (1999) treated 12 plant species with 10 trace elements (As, B, Cd, Cr, Cu, Pb, Mn, Hg, Ni and Se) and found that with the exception of B, all trace elements studied accumulated to substantially higher concentrations (from 5 to 60 folds) in roots than in shoots of all plant species.

As mentioned before the translocation ability (TA) is the ratio between the concentration of a trace element accumulated in the root tissues by that accumulated in shoot tissues, a larger ratio implies poorer translocation capability. In this study the ratio results were in the order of Ni > Cu > Zn (Figure 8). Although the concentrations of Cu and Ni exceeded Zn in the water environment, the translocation of Cu & Ni to the shoots was less than that of Zn.

In this aspect Barry and Clark, (1978) mentioned that Zn was found to be more mobile from roots to shoots than other elements such as copper. Vesk *et al.* (1999) explained the low leaf concentration of Cu & Pb compared with Zn in water hyacinth plant by the possibility of the distribution of the two metals at a low concentration over a large biomass. Baldantoni *et al*. (2008) found that both in *Phragmites communis* and in *Najas marina* Zn appeared to be more mobile than Cu, since its concentration ratios between roots/leaves and roots/shoots (4.2 and 1.6) were lower than those for Cu (11.5 and 2.0). Brun *et al.*, (2001) recorded that in most of the species studied to date, it has been found that there is a strong barrier to translocation of Cu; hence Cu tends to be largely accumulated in fibrous plant roots rather than in other plant parts which are more usually consumed.

The mobility of nickel in plants varies between species, from mobile in some plants (Tiffin, 1971 & Thiesen and Blincoe, 1988) to immobile in others (Sajwan, *et al*., 1996). Ni was found to be immobile in *Phragmites communis*, where it showed a concentration in roots 48 fold higher than in leaves (Baldantoni, *et al*., 2008). On the same line with the present study Weiliao and Chang (2004) concluded that water hyacinth absorbed the heavy metals Cd, Pb, Cu, Zn, and Ni mostly from the roots and translocated only 6 to 25% to the shoots.

Correlation Coefficient:

Table (5) represents the correlation coefficient between Cu, Ni and Zn concentrations in ambient water and their accumulation and bioconcentration in roots and shoots of water hyacinth plant. The concentrations of the three trace metals in water were positively correlated with the amount accumulated in plant roots.

For Cu, significant differences ($r < 0.05$) were found between a) Cu concentration in water and amounts of Cu accumulated in plant roots & shoots, b) amount of Cu accumulated in plant roots & that accumulated in plant shoots.

Table 5: Correlation Coefficient between Cu, Ni and Zn Concentrations in Water and their Bioaccumulation and Bioconcentration in Roots and Shoots of Water Hyacinth Plant.

	Cu-w	**Cu-r**	**Cu-s**	**BCF Cu-r**	**BCF Cu-s**
Cu-w	1.00				
Cu-r	0.95*	1.00			
Cu-s	0.93*	0.96*	1.00		
BCF Cu-r	-0.15	0.144	0.15	1.00	
BCF Cu-s	-0.45	-0.24	-0.106	0.86	1.00
*Correlation is significant at the 0.05 level					
	Ni-w	**Ni-r**	**Ni-s**	**BCF Ni-r**	**BCF Ni-s**
Ni-w	1.00				
Ni-r	0.958*	1.00			
Ni-s	0.282	0.478	1.00		
BCF Ni-r	0.915*	0.976**	0.627	1.00	
BCF Ni-s	-0.037	0.182	0.948*	0.352	1.00
**Correlation is significant at the 0.01 level *Correlation is significant at the 0.05 level					
	Zn-w	**Zn-r**	**Zn-s**	**BCF Zn-r**	**BCF Zn-s**
Zn-w	1.00				
Zn-r	0.963**	1.00			
Zn-s	0.975**	0.996**	1.00		
BCF Zn-r	0.860	0.963**	0.942*	1.00	
BCF Zn-s	0.478	0.683	0.661	0.812	1.00
**Correlation is significant at the 0.01 level *Correlation is significant at the 0.05 level					

For Ni, significant differences ($r < 0.05$) were found between a) Ni concentration in water and amount of Ni accumulated in plant roots, b) Ni concentration in water & BCF of Ni in plant roots, c) BCF of Ni in plant shoots and amount of Ni accumulated in plant shoots. While a highly significant difference ($r < 0.01$) recorded between BCF of Ni in plant roots and amount of Ni accumulated in plant roots.

For Zn a highly significant difference ($r < 0.01$) recorded between: a) Zn concentration in water and amounts of Zn accumulated in both plant roots & shoots, b) amount of Zn accumulated in plant roots & that accumulated in plant shoots, c) BCF of Zn in plant roots and amount of Zn accumulated in plant roots. On the other side a significant difference ($r < 0.05$) was found between BCF of Zn in plant roots and amount of Zn accumulated in plant shoots.

Parallel to the above mentioned results, Weiliao and Chang (2004) found that Cd, Pb, Cu, Zn, and Ni concentrations in water were positively correlated with the amount accumulated in water hyacinth roots. Soltan and Rashed, (2003) mentioned that; laboratory studies on water hyacinth have demonstrated the potential use of this species in removing metals from polluted water and have shown that metal concentrations of the plant and the water column are correlated.

Jones, *et al*. (1985) stated that strong positive associations between the metal concentrations in a plant and in its environment suggest that this plant has the potential for monitoring pollution in general and monitoring the metal examined in particular.

Conclusion:

- Cu, Ni and Zn concentrations in water at all the studied locations were below the standard limits of the Egyptian environmental law 9/2009, indicating no impact from the two drains' discharges on the downstream of River Nile with respect to these metals.
- Metal content of water hyacinth can serve as a good bioindicator of metal pollution in different aquatic environments.
- Water hyacinth plants were able to accumulate higher amounts of Cu, Ni and Zn in their roots to levels exceeding the normal ranges stated in plants, thus it is recommended to be employed in the phytoremediation of these metals from aquatic habitats or constructed wetlands.
- It is recommended that water hyacinth roots should be removed before using the plant in fodder or co-compost organic fertilizer to prevent food chain contamination.
- The accumulation & translocation potential of Zn by water hyacinth was higher than that of Cu and Ni.
- Based on BCF values of the three metals in plant roots, water hyacinth can be primarily utilized as a good phytoaccumulator of Zn followed by Cu then by Ni.
- Significant correlations recorded between Cu, Ni and Zn concentrations in ambient water and their bioaccumulation and bioconcentration in water hyacinth tissues suggest that water hyacinth plant may be very useful for monitoring these polluting metals.

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REFERENCES

Abd El-Hady, B.A., 2007. Compare the effect of polluted and River Nile irrigation water on contents of heavy metals of some soils and plants, Research Journal of Agriculture and Biological Sciences, 3(4): 287-294.

Abd-Elhamid, M., 1996. Study on the uptake of some heavy metals by some plants. M.Sc.Thesis, Fac. Agric., Cairo Univ.

Abd-Elmoniem, E.M., 2003. Response of hyper and non-hyper accumulator plants to nickel element, Annals. Agric. Sci., Moshtohor, 41: 1701-1710.

Abdel-sabour, M.F., 2010. Water hyacinth: Available and renewable resource, Electronic Journal of Environmental, Agricultural and Food Chemistry, 9(11).

APAH., 2005. American Public Health Association Standard Methods for the Examination of Water and Wastewater, 21^{th} ed., American Public Health Association Inc., New, York, N.Y.

Baker, A.J.M. and P.L. Walker, 1989. Ecophysiology of metal uptake by tolerant plants, In: Heavy metal tolerance in plants – Evolutionary aspects, Shaw A. (eds). CRC Press, 155-177.

Baldantoni, D., A. Alfani, P.D. Tommasi, G. Bartoli, A.V. De Santo, 2004. Assessment of macro and microelement accumulation capability of two aquatic plants, Environmental Pollution, 130: 149-156.

Barry, S.A.S. and S.C. Clark, 1978. Problems of interpreting the relationship between the amounts of lead and zinc in plants and soil on metalliferous wastes, New Phytologist, 81: 773-783.

Black, H., 1995. Absorbing possibilities: Phytoremediation, Environ. Health Persp., 103: 1106-1108.

Bowen, H.J.M., 1979. Environmental chemistry of the elements, Academic Press, London.

Brun, L.A., J. Maillet, P. Hinsinger, M. Pépin, 2001. Evaluation of copper availability to plants in copper contaminated vineyard soils, Environmental Pollution, 111(2): 293-302.

Brune, A., W. Urbach, K.J. Dietz, 1994. Compartmentation and transport of zinc in barley primary leaves as basis mechanisms involved in zinc tolerance, Plant Cell Environ., 17: 153-62.

Carvalho, K.M. and D.F. Martin, 2001. Removal of aqueous selenium by four aquatic plants, Journal of Aquatic Plant Management, 39: 33-36.

Chaney, R.L., M. Malik, Y.M. Li, S.L. Brown, J.S. Angle, A.J.M. Baker, 1997. Phytoremediation of soil metals, Curr. Opin. Biotechnol., 8(3): 279-84.

Chapman, H.D. and P.F. Pratt, 1961. Methods of analysis for soils, plants and water, Univ. California, Berkeley, CA, USA.

Deng, H., Z.H. Yea, M.H. Wong, 2004. Accumulation of lead, zinc, copper and cadmium by 12 wetland plant species thriving in metal-contaminated sites in China, Environmental Pollution, 132: 29-40

Ensley, B.D., 2000. Rationale for the use of phytoremediation, phytoremediation of toxic metals: Using plants to clean-up the environment, John Wiley Publishers, New York.

Hampp, R., K. Beulich, H. Ziegler, 1976. Effect of zinc and cadmium on photosynthetic CO2-fixation and Hill activity of isolated spinach chloroplasts, Z Pflanzenphysiol., 77: 336-44.

Jadia, C.D. and M.H. Fulekar, 2009. Phytoremediation of heavy metals: Recent techniques, African Journal of Biotechnology, 8(6): 921-928.

Jana, S., 1988. Accumulation of Hg and Cr by three aquatic species and subsequent changes in several physiological and biochemical plant parameters, Water Air Soil Pollut., 38: 105-109.

Jones, K.C., 1985. Gold, silver and other elements in aquatic bryophytes from a mineralized area of North Wales, U.K., J. Geochem. Explor., 24: 237-246.

Kabata-Pendias, A. and H. Pendias, 2001. Trace elements in soils and plants, CRC Press, London.

Khan, S.U. and A. Moheman, 2006. Effect of heavy metals (Cadmium and Nickel) on the seed germination, growth and metals uptake by chilli (*Capsicum frutescens*) and sunflower plants (*Helianthus annuus*), Poll. Res., 25(1): 99-104.

Lasat, M.M., 2000. Phytoextraction of metals from contaminated soil: a review of plant/soil/metal interaction and assessment of pertinent agronomic issues, J Hazar. Subs. Res., 2: 1-23.

Levesque, R., 2007. SPSS Programming and Data Management: A Guide for SPSS and SAS Users, Fourth Edition, SPSS Inc., Chicago Ill.

Lin, Y.X. and X.m. Zhang, 1990. Accumulation of heavy metals and the variation of amino acids and protein in *Eichhornia crassipes* (Mart.) solms in the Dianchi lake, Oceanol. Limnol. Sinica., 21: 179-84.

Lu, X., M. Kruatrachue, P. Pokethitiyook, K. Homyok, 2004. Removal of cadmium and zinc by water hyacinth, *Eichhornia crassipes*, Science Asia, 30: 93-103.

Lyngby, J.E. and H. Brix, 1982. Seasonal and environmental variation in cadmium, copper, lead and zinc concentrations in eelgrass *Zostera marina* L., Limfjord. Aquat. Bot, 14: 59-74, Denmark.

Meagher, R.B., 2000. Phytoremediation of toxic elemental and organic pollutants, Current Opinion in Plant Biology, 3: 153-162.

Narain, S., C.S.P. Ojha, S.K. Mishra, U.C. Chaube, P.K. Sharma, 2011. Cadmium and chromium removal by aquatic plant, International Journal of Environmental Sciences, 1(6).

Qian, J.H., A. Zayed, Y.L, Zhu, M. Yu, N. Terry, 1999. Phytoaccumulation of trace elements by wetland plants: III. Uptake and accumulation of ten trace elements by twelve plant species, J. Environ. Qual., 28: 1448-55.

Rai, U.N. and P. Chandra, 1992. Accumulation of copper, lead, manganese and iron by field population of *Hydrodictyon reticulatum* Lagerheim, Sci. Total Environ., 116: 203-11.

Robb, D.A. and W.S. Pierpoint, 1983. Metals and Micronutrients: Uptake and Utilisation by Plants, Academic Press, London.

Rugigana, J.K., 2007. Zinc and chromium removal mechanisms from industrial wastewater by using water hyacinth (*Eicchonia crassipes)*, Master's in WREM (water resources and environmental management), National University of Rwanda.

Sajwan, K.S., W.H. Ornes, T.V. Youngblood, A.K. Alva, 1996. Uptake of soil applied cadmium, nickel and selenium by bush beans, Water Air and Soil Pollution, 91: 209-217.

Soltan, M.E. and M.N. Rashed, 2003. Laboratory study on the survival of water hyacinth under several conditions of heavy metal concentrations, Adv. Environ. Res., 7: 321-34.

Stratford, H.K., T.H. William, A. Leon, 1984. Effects of heavy metals on water hyacinths (*Eichhornia crassipes*), Aquat. Toxicol., 5(2): 117-28.

Thiesen, M.O. and C. Blincoe, 1988. Isolation and partial characterization of nickel complexes in higher plants, Biological Trace Element Research, 16: 239-251.

Tiffin, L.O., 1971. Translocation of nickel xylem exudate of plants, Plant Physiology, 48: 273-277.

Tolg, G., 1974. The basis of trace analysis, 1: 698-710, In E. Korte (Ed.), Methodium chimicum, Analytical methods, part b, Micromethods, biological methods, quality control, automation, Academic press, New York.

USPA., 2000. United States Protection Agency, EPA 600/R-99/107: Introduction to phytoremediation, U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.

Vesk, P.A., C.E. Nockolds, W.G. Allaway, 1999. Metal localization in water hyacinth roots from an urban wetland, Plant, Cell and Environment, 22: 149-158.

Wang, W.C. and M.A. Lewis, 1997. Metal accumulation by aquatic macrophytes, In: Plants for Environment Studies (Edited by Wang WC, Gorsuch JW and Hughes JS), 367-416. Lewis Publishers, New, York.

Weiliao, S. and W.L. Chang, 2004. Heavy metal phytoremediation by water hyacinth at constructed wetlands in Taiwan, J. Aquat. Plant Manage., 42: 60-68.

Wu, F.Y. and E.J. Sun, 1998. Effects of copper, zinc, nickel, chromium and lead on the growth of water convolvulus in water culture, Environ. Prot., 21(1): 63-72.

Yahya, M.N., 1990. The absorption of metal ions by *Eichhornia crassipes*, Chemical Speciation and Bioavailability, 2: 82-91.

Zaranyika, M.F. and T. Ndapwadza, 1995. Uptake of Ni, Zn, Fe, Co, Cr, Pb, Cu and Cd by water hyacinth (*Eichhornia crassipes*) in Mukuvisi and Manyame rivers, Zimbabwe, J. Environ. Sci. Health, Part A Environ. Sci. Eng. Toxic Hazardous Substance Control, 30: 157-69.

Zayed, A., S. Gowthaman, N. Terry, 1998. Phytoaccumulation of trace elements by wetland plants: I. Duckweed, Environ. Qual., 27: 715-21.

Zhu, Y.L., A.M. Zayed, J.H. Qian, M. Souza, N. Terry, 1999. Phytoaccumulation of trace elements by wetland plants: Water Hyacinth, J. Environ. Qual., 28: 339-344.