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Case Report

Phytoremediation of industrial wastewater potentiality by *Typha domingensis*

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ABSTRACT: Phytoremediation is increasingly receiving attention as a cost effective technique that uses plants to remediate contaminants from wastewater, soil and sediments. In this study, the ability of *Typha domingensis* to uptake heavy metals as well as its potential application for phytoremediation was assessed. Pollutant elements concentrations were measured in samples of wastewater, sediments and *Typha domingensis* collected from industrial wastewater ponds, El-Sadat city, Egypt. This study specifically focused on the capacity of *Typha domingensis* to absorb and accumulate aluminum, iron, zinc and lead. Results indicated that*Typha domingensis* was capable of accumulating the heavy metal ions preferentially from wastewater than from sediments. The accumulation of metals in plant organs attained the highest values in roots, rhizomes and old leaves. Rhizofiltration was found to be the best mechanism to explain *Typha domingensis* phytoremediation capability.

Keywords: *Aluminium; Bioconcentration factor; El-Sadat city; Iron; Lead; Rhizofiltration; Translocation factor; Zinc*

INTRODUCTION

The industrial sector is an important consumer of both natural resources and a contributor to environmental pollution. The spatial distribution of industry in Egypt is influenced by the size of the employment pool, availability of services, access to transportation networks and proximity to principal markets. The manufacturing facilities are therefore often located within the boundaries of major cities as Greater Cairo and Alexandria.

The program of Eco-friendly industrial cities (Hamza, 2001) launched by the Egyptian government aims at boosting various initiatives of cleaner production in the industrial establishments. One of the important new industrial Egyptian cities is El-Sadat city located between Cairo and Alexandria by the kilo 93 Cairo / Alexandria desert road. The main economic bases in the city, which has an area of 500 km^2, are industrial activities. The industry sector includes many important activities which are: iron (Fe^{3+}) and steel, yarn and textile dying, building and construction, food products and beverage, ready made garments, engineering and metal production, electronics and electricity ware, wood products and furniture, plastic products and chemicals, transport equipments, paper products, poultry, industrial gases and medical products.

Discharge of untreated or partially treated industrial and domestic wastewater, leaching of pesticides and residues of fertilizers and transportation activities are the most important factors that affect the quality of ground and nearby surface water bodies (Ezzat *et al.*, 2002). In Egypt, the degradation of water quality is a major issue, particularly; industrial discharges produce high levels of pollutants that can subsequently contaminate the soil, sediments and surface water systems (Förstner and Salomons, 1991; Dekov, 1997; Evangelou, 1998). As such there has been a great deal

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of research into finding cost effective methods for the removal of contaminants from wastewater (Abdel-Ghani *et al*, 2008; Al-Anber *et al*, 2008). Phytoremediation methods are comparatively cheap and ecologically advantageous, compared to other common technological approaches. There are several species of plants known for their phytoremediative abilities (Riffat *et al*, 2007; Nouri *et al.*, 2009; 2011). The phytoremediation potentials of plant species have been considered in many previous researches (Sharifi *et.al*, 2007; Singh *et.al*, 2007; Zhang *et.al*, 2009).

Typha domingensis the subject of the present study is a widespread and dominant plant species in many aquatic systems in Egypt. *T. domingens is* is a tall (2.0–2.5 m) perennial marsh that occurs naturally in both pristine and disturbed habitats with widely fluctuating water levels (Boulos, 2009), such as the industrial wastewater ponds in El-Sadat city, Egypt. This species can act as an aggressive invader and can completely choke lakes, ditches and canals.

The objectives of the present study were: 1) to evaluate the uptake and accumulation of metal pollutants in different organs of *T. domingensis* growing in industrial wastewater ponds and 2) to assess the correlations between metal pollutants content in wastewater sediment plant system as an important asset for potential use of the species in phytoremediation of industrial wastewaters. The study was carried out during 2009 at El-Sadat city, Egypt.

MATERIALS AND METHODS

Study area

The study area is located in the industrial zone of El-Sadat city in Menoufia governorate, Egypt (latitude 30° 22' 30''N and longitude 30° 30' 1''E).

Collection of wastewater, sediments and plant samples

Grab samples of wastewater were collected from the main wastewater pond that received the direct industrial effluent at the study area (David *et al.*, 2007). Wastewater samples were digested following the "nitric acid digestion procedure" described by APHA *et al.* (1998).

Sediment samples were collected from the study area (about 30 cm depths) then air dried to constant weight and then sieved through 2 mm stainless steel sieve. After homogenization, samples were kept in paper bags and preserved in desiccators for analysis. The sediment pH was determined potentiometrically in 1:2.5 (sediment: de-ionized water suspension) ratio (Maria *et al*., 2008). Sediment samples were digested following the "AOAC official method 990.08" described by AOAC (2002a).

T. domingensis plants were collected from the study area and separated into rhizomes and roots, leaf bases, leaf green parts and yellow leaf parts. Plant tissue samples were thoroughly washed with running tap water and rinsed with deionized water to remove any sediment particles attached to the plant surfaces. Plant tissue samples were macerated and oven dried at 70 °C to constant weight, then the dried materials were ground into powder and preserved in paper bags in a desiccator for subsequent analysis. The samples were digested following the procedure described by the "AOAC official method 985.01" described by AOAC (2002b).

Determination of metals

Metals concentrations in the wastewater, sediment and plant samples were determined by Inductively Coupled Plasma ICP-OES (Perkin Elmer, Optima 2000 DV) using argon and nitrogen gases. The instrument working wavelengths were set as suggested by the APHA *et al*. (1998).

Evaluation of phytoremediation parameters

The Bioconcentration factor (BCF) is a dimensionless factor also called bioaccumulation factor or enrichment coefficient, was calculated as the ratio of a given element concentration in the plant tissues at harvest to the concentration of the element in the external environment according to Eq.1 (Sutapa and Bhattacharyya, 2008)

$$BFC = P/E \quad (1)$$

Where P represents the element concentration in plant tissues (mg/kg dry wt t) and E represents the element concentration in the water (mg/L) or in the sediment (mg/kg dry wt). A larger ratio implies better phytoaccumulation capability.

Translocation factor (TF) was calculated by dividing the concentration of a trace element accumulated in the root tissues by that accumulated in shoot tissues (Sutapa and Bhattacharyya, 2008). TF is given by Eq. 2.

$$TF = (A_s / A_r) \quad (2)$$

Where A_r represents the amount of trace element accumulated in the roots (mg/kg dw) and A_s represents the amount of trace element accumulated in the shoots (mg/kg dw). TF is also called translocation capability and is dimensionless factor where a larger ratio implies higher translocation capability.

Statistical analysis

All analysis results (average of four replicates) were subjected to statistical treatment to determine the mean, standard deviation, relative standard deviation, significance and correlation coefficients. All statistics were calculated using Microsoft Excel 2007 and the SPSS 11.0.

RESULTS AND DISCUSSION

Wastewater analysi

The wastewater analysis results are shown in Table 1. All pollutant concentrations determined in the different wastewater samples were directly compared to the Egyptian environmental legal requirements for industrial wastewater (EEAA, 1994; EEAA, 2002; Daifullah *et al*., 2003). High levels of total dissolved solids (TDS) were quantified in the industrial wastewater pond (Table 1). The EPA suggests a maximum level of 250 mg/L in fresh water to minimize harm to humans and aquatic life (US EPA, 2001). Although a range of TDS concentrations are natural within aquatic systems, the high values observed in the wastewater ponds for the present study are likely due to anthropogenic wastewater releases by local residents or industry (Janel and Emily, 2006).

Nutrient concentrations in wastewater tend to be highly variable and industry-specific. Wastewater from industrial effluent often contains nitrogen (N) and phosphorus (P) concentrations in excess of 200 and 20 mg/L, respectively (Phillips, 2002). Increased amounts of nitrogen and phosphorus found in wastewater ponds are the result of industrial wastewater discharge (Yale Center for Environmental Law and Policy, 2008). Among cations that occur abundantly in wastewater (Na^+, Ca^{2+}, Mg^{2+} and K^+), sodium was the most abundant whereas magnesium had the lowest concentration (Table 1).

Four metal ions in this study exceeded the permissible limits indicated by the Egyptian environmental regulations (Daifullah *et al*., 2003) (EEAA, 1994; 2002) for wastewater discharge. Based on these results, further experiments were focused on the following four metal ions viz., aluminum (Al^{3+}), Fe^{3+}, zinc (Zn^{2+}) and lead (Pb^{2+}).

The presence of large amounts of Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} is related to the major industries existing in the city. These include iron and steel production factory which accounts for the high level of Fe^{3+} found in wastewater, Al^{3+} presence may be attributed to the presence of food products and beverage facilities, whereas the presence of electronics and electricity industrial activities could be the responsible for the existence of Zn^{2+} and Pb^{2+} (Evangelou, 1998).

Sediments analysis

Sediments act as sinks for many contaminants, however the presence of elevated contaminant concentrations in sediments may have implications to the integrity of ecological systems (Mercedes *et al*., 1998).The sediment pH was found to be slightly alkaline with a value of 7.50 which is suitable for the growth of many plant species (Lindsay, 1979). The sediment samples were then analyzed for their Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} contents. Table 2 demonstrates a comparison between the tested metal ions concentrations in sediments and the common, critical and ecotoxic ranges of metals in soils and sediments.

As can be seen from Table 2, the critical amounts of Zn^{2+} and Pb^{2+} ions are present in the sediments. The investigated lake sediments exceeded the upper eco-toxic threshold value limits for Zn^{2+} and Pb^{2+} as established by the U. S. Environmental Protection Agency in the sediment (US EPA, 1996). These two metals also were in the critical concentration range of metals in soils (Kabata and Pendias, 1992). Equilibrium exists between sediments and water, as such sediment acts as the ultimate repository for many contaminants. Thus, in order to correlate the water and sediments content of the metal ions, Pearson's correlation coefficients were calculated. The correlation coefficients were found to be: Al_s/Al_w (1.00), Fe_s/Fe_w (0.977), Zn_s/Zn_w (0.968) and Pb_s/Pb_w (0.808) indicating that all the studied metals concentrations in water and sediments are positively correlated implying that Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} are from the same source or origin.

Plant analysis

Typha domingensis plant samples were collected from the study area at two different seasons (Winter and Summer 2008). Plant samples were separated into four parts namely 1) Roots and rhizomes, 2) Leaf bases, 3) Green leaf parts and 4) Yellow leaf parts. Control *T. domingensis* plant samples were also collected from

Table 1: Mean and ±SD of elemental and physicochemical characteristics of wastewater

Measured parameter	Concentration in mg/L
TDS	1396
Total Kjeldahl N	531.5
Total P	5.32±0.02
Na^{+}	377.10 ±13.6
Mg^{2+}	30.83 ±1.2
K^{+}	34.41 ±1.5
Ca^{2+}	75.97 ±4.0
Al^{3+}	6.56 ±0.4**
Cr^{3+}	0.11 ±0.02
Mn^{2+}	0.17 ±0.03
Fe^{3+}	10.46 ±0.28**
Ni^{2+}	0.02 ±0.007
Cu^{2+}	0.29 ±0.06
Zn^{2+}	3.87 ± 0.09**
As^{3+}	ND*
Cd^{2+}	ND*
Pb^{2+}	0.99 ±0.01**

*ND = not detected; ** Higher than the limits of the Egyptian environmental regulations which are 3, 1.5, 1 and 0.05 mg/L for Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} respectively. ND = not detected

unpolluted area nearby the study area. No yellow leaf parts were found in the control samples.

A graphical comparison for the accumulation of Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} in different *Typha* parts during Summer and Winter seasons as compared to control is given in Fig. 1 and the results are summarized in Table 3.

It was also observed that all the studied elements concentrations in different plant parts were significantly higher ($p< 0.05$) in Summer than in Winter.

The statistical analysis results for the comparison of means for control, Winter and Summer elements concentrations in different *T. domingensis* parts showed that Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} concentrations in plant tissues from the wastewater pond were significantly higher ($p< 0.05$) than in the control plant.

Further the statistical analysis for the comparison of mean elements accumulation in different plant parts in the wastewater pond showed that: 1) Al^{3+} accumulation varied significantly ($p<0.05$) between the different *T. domingensis* parts following the order: yellow parts> roots and rhizomes> leaf bases> green parts; 2) Fe^{3+} and Zn^{2+} accumulated in the order: roots and rhizomes> leaf bases> yellow parts> green parts; with significant differences ($p<0.05$), except between yellow and green leaf parts; and 3) Pb^{2+} accumulation varied significantly ($p<0.05$) following the order: roots and rhizomes> leaf bases> green parts >yellow parts, with no significant differences between the accumulation in yellow and green leaf parts.

Comparing the elements concentrations accumulated by different *T. domingensis* parts with the phytotoxic values previously reported in literature showed that aluminium concentration in all plant parts (except the green parts) exceeded the phytotoxic limit for aluminium in plants which is >100 mg/Kg (Dobermann and Fairhurst, 2000). Many toxic effects of aluminium on plant growth have been previously reported. Among the toxic effects of Al^{3+} on plants is the reduction of chlorophyll pigment quantity as well as the ratio between chlorophyll a and b, which is accompanied by a marked decline in photosynthetic rate (Ajoy *et al*., 1998). These phenomena could be occurring in plants in the wastewater pond and be responsible for the observed yellowing of leaf parts.

Interestingly, the levels of Fe^{3+}, Zn^{2+} and Pb^{2+} in the plant parts did not exceed the phytotoxic limit for these elements, which are in the range 400-1000 mg/Kg, 200-500 mg/Kg and 30-300 mg/Kg for Fe^{3+}, Zn^{2+} and Pb^{2+} respectively (Levy *et al*., 1999; Romheld and Marschner, 1991).

BCF and TF

After analyzing the results of Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} accumulation by different plant parts, two important factors were studied to understand the possible role of *T. domingensis* in phytoremediation. The two investigated factors are 1) the TF and 2) BCF, also called enrichment coefficient. Both BCF and TF can be used to estimate a plant's potential for phytoremediation purpose (Yoon, 2006).

TFs are used to determine the effectiveness of a plant in the translocation of metals from the roots to the shoots (Tu and Ma, 2002). Both the BCF and the TF are considered when investigating whether a plant is a hyperaccumulator of a metal (Gonzaga *et al*., 2006). When BCFs >1 indicate that the plant is an "accumulator", <1 indicate the plant is an "excluder" (Baker, 1981). TFs > 1 indicate the plant is effective in the translocation of a metal from root to shoot tissue (Ma *et al*., 2001). The TF of the studied elements are shown in Table 4. The TF values ranged between 0.118 and 0.357. The TFs for the studied elements were generally lower than 1.0 indicating that *T. domingensis*

Table 2: Comparison between the tested metals concentration in sediments and the normal; critical ranges of metals in soils and sediments, and eco-toxic ranges of metals in sediments

Metal ions	Concentration in tested samples (mg/Kg)	Common range in soils (mg/Kg)*	Critical range in soil (mg/Kg)**	Eco-toxic threshold values in sediments (mg/Kg)***
Al^{3+}	2879.50 ± 45.7	10,000-300,000	-	-
Fe^{3+}	5264.75 ±25.7	7,000-550,000	-	-
Zn^{2+}	904.35 ± 11.1	10-300	70-400	47
Pb^{2+}	59.13 ± 2.3	2-200	30-300	150

* Naturally occurring in the soil (Denga *et al*., 2004);** Data after Kabata and Pendias (Kabata and Pendias, 1992); ***Ecotoxic threshold values established by EPA in the sediment (EPA, 1996)

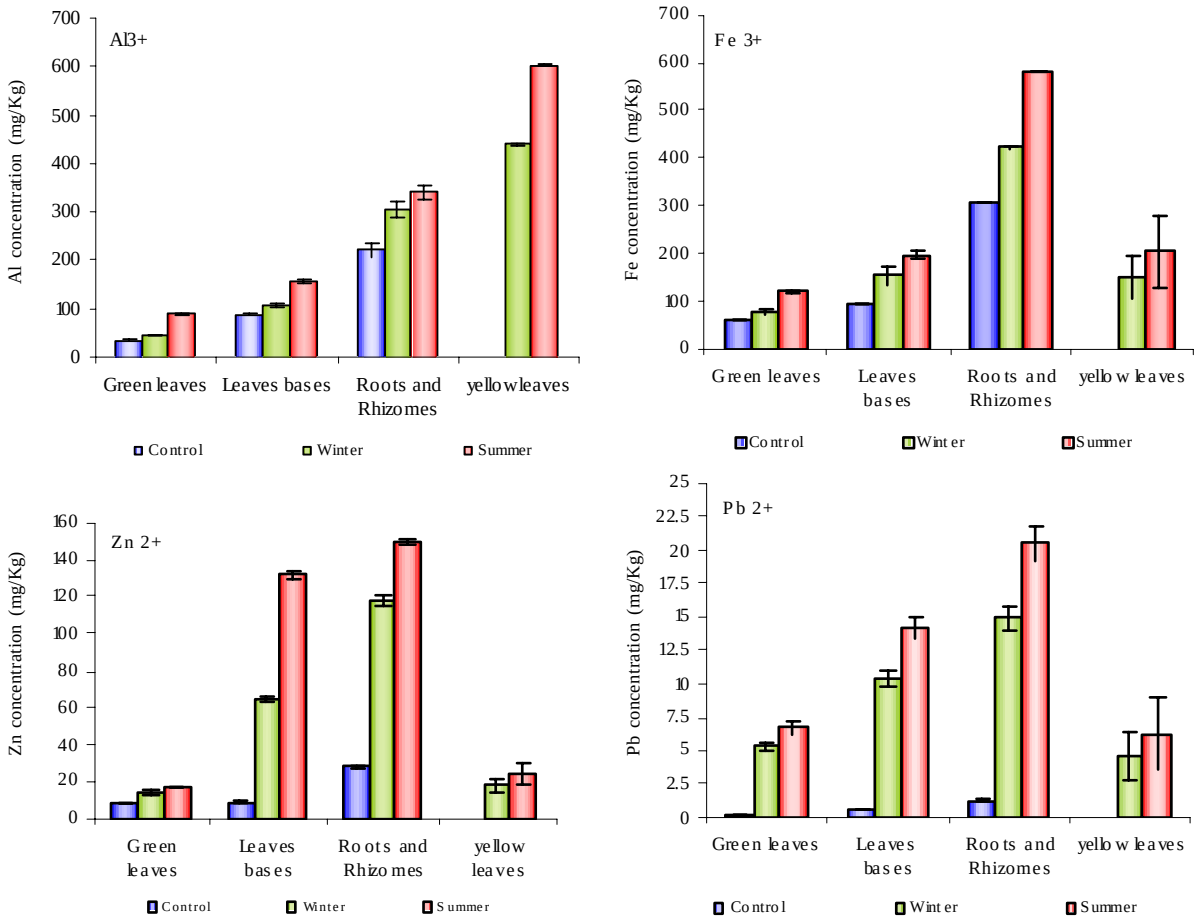

Fig. 1: Accumulation of Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} in different plant parts in Summer and Winter seasons

did not effectively transfer the studied elements from root to shoot i.e. the plant accumulates metals in the below ground parts (roots / rhizomes) better than in the above ground parts (shoot / leaf). The uptake ability for the roots of *T. domingensis* towards the studied elements was in the following order: $Pb^{2+} > Fe^{3+} > Al^{3+} > Zn^{2+}$

BCF is a common important factor when considering the phytoremediation potential of a given species (Zhao *et al*., 2003). In this study, BCF values of Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} (Table 4), were greater than 1 which indicated the phytoremediation potential of *T. domingensis* for these metals. Baker (1981) concluded that any species may act as an accumulator, an indicator and excluder

Table 3: Mean values and ±SD of concentrations in different plant parts of *T. domingensis* growing in control site and industrial wastewater pond in different seasons

Element	Elements concentrations in control plant (mg/Kg)			Elements accumulation in *Typha* parts in Winter (mg/Kg)				Elements accumulation in *Typha* parts in Summer (mg/Kg)			
	Roots and rhizomes	Leaf bases	Green parts	Roots and rhizomes	Leaf bases	Green parts	Yellow parts	Roots and rhizomes	Leaf bases	Green parts	Yellow parts
Al^{3+}	220.82 ± 13.52	87.64 ±1.08	34.60 ± 0.52	303.91 ± 16.12	106.92 ±3.03	44.25 ± 0.66	439.8 ± 2.03	350.55 ± 13.71	156.55 ±2.86	89.18 ± 2.91	602.39 ± 3.21
Fe^{3+}	307.5 ±0.89	95.76 ± 0.28	62.42 ± 2.15	423.20 ±1.07	154.68 ± 21.5	78.83 ± 2.70	148.89 ± 46.38	582.44 ±1.70	196.68 ± 8.28	119.76 ± 1.65	203.94 ± 73.35
Zn^{2+}	28.06 ± 1.04	9.12 ± 0.08	7.46 ±0.31	117.64 ± 2.26	63.90 ± 1.86	13.95 ±1.19	17.89 ±3.86	149.60 ± 0.89	131.63 ± 2.96	17.44 ±0.25	24.50 ±5.83
Pb^{2+}	1.26 ± 0.13	0.65 ±0.01	0.047 ±0.01	14.87 ± 0.83	10.36 ±0.596	5.30 ±0.36	4.61 ±1.75	20.46 ± 1.33	14.19 ±0.82	6.78 ±0.46	6.32 ±2.77

The data presented are mean values of four replicates ± standard deviation

Table 4: BCF and TF of Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+}

Metals	BCF (shoot / sediment)	BCF (root / sediment)	BCF (shoot / wastewater)	BCF (root / wastewater)	TF (shoot / root)
Al^{3+}	0.015±0.0004	0.105±0.004	6.78±0.55	46.37±1.28	0.146±0.01
Fe^{3+}	0.015±0.0005	0.080±0.004	7.63±0.42	40.48±1.03	0.188±0.01
Zn^{2+}	0.015±0.0014	0.130±0.001	3.61±0.34	30.37±0.15	0.118±0.01
Pb^{2+}	0.089±0.0027	0.251±0.010	5.43±0.60	15.27±2.04	0.357±0.02

over different ranges of soil metal concentration. This factor indicates that *T. domingensis* is an effective metal accumulator.

The correlation coefficients of element concentrations in water, sediment and plant demonstrated a small number of significant, positive relationships (Table 5). In general, there were higher correlations between the concentrations of studied elements in *T. domingensis* roots and in water than in sediments. The results obtained in the present study were in agreement with the results reported in literature by Sasmaz *et al*. (2008) and Sutapa *et al*. (2008) for other *Typha* species.

Previous studies on the accumulation of various metal ions by aquatic plants have also shown that the accumulation of most metals was higher in roots than the other parts of plants (Satyakala and Jamil, 1992; Zaranyika and Ndapwadza, 1995; Chandra and Kulshreshtha, 2004). This is consistent with the findings of the present study.

These results further support the efficacy of *T. domingensis* in phytoremediation purposes. Phytoremediation comprises different strategies used by plants to decontaminate soil and water, namely, rhizofiltration, phytostabilization, phytodegradation, phytoextraction, and phytovolatilization (US EPA, 1998).

The results could be explained in terms of "*rhizofiltration*" which involves the removal of aqueous pollutants by the plant root system (Dushenkov , 1995; Dushenkov and Kapulnik, 2000). Rhizofiltration is a promising alternative to the conventional clean-up methods, a phytoremediative technique designed for the removal of metals in aquatic environments. The process involves raising plants hydroponically and transplanting them into metal-polluted waters where plants absorb and concentrate the metals in their roots and shoots (Dushenkov *et al*., 1995 ; Salt *et al*., 1995; Flathman and Lanza, 1998; Zhu *et al*.,1999). Root exudates cause changes in rhizosphere pH and may cause metals to precipitate onto root surfaces. As they become saturated with the metal contaminants, roots or whole plants are harvested for disposal (Flathman and Lanza, 1998; Zhu *et al*.,1999).

Fig. 2 shows the pathway of metals uptake in plants (Wendy *et al*., 2005). For many contaminants, passive uptake via micropores in the root cell walls (the apoplastic pathway) may be a major route into the root, where sequestration or degradation can take place. The

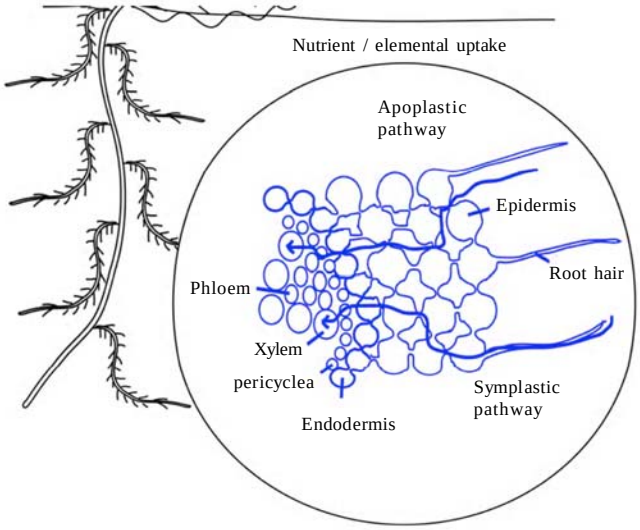

Fig. 2: Pathway of metals uptake in plants (Wendy *et al*., 2005)

Table 5: Correlation matrix between elements concentrations in water, sediment and plant

		Al_W	Al_S	Al_{pr}	Al_{ps}
Al^{3+}	Al_W	1			
	Al_S	1.000**	1		
	Al_{pr}	0.946	0.942	1	
	Al_{ps}	-0.370	-0.348	-0.468	1
Fe^{3+}		Fe_W	Fe_S	Fe_{pr}	Fe_{ps}
	Fe_W	1			
	Fe_S	0.977**	1		
	Fe_{pr}	0.545	0.568	1	
	Fe_{ps}	-0.663	-0.602	0.028	1
Zn^{2+}		Zn_W	Zn_S	Zn_{pr}	Zn_{ps}
	Zn_W	1			
	Zn_S	0.968*	1		
	Zn_{pr}	0.980*	0.984*	1	
	Zn_{ps}	-0.429	-0.463	-0.325	1
Pb^{2+}		Pb_W	Pb_S	Pb_{pr}	Pb_{ps}
	Pb_W	1			
	Pb_S	0.808	1		
	Pb_{pr}	0.990**	0.507	1	
	Pb_{ps}	0.883	0.635	0.559	1

**Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed), where: M_w, M_S, M_{pr} and M_{ps} are metal ion (M) concentrations in water, sediment, plant roots and plant shoots, respectively

apoplast is a hydrated free space continuum between the external soil solution and the cell membranes of the root cortex and vascular tissue. The cell wall micropores exist within a network of cellulose, hemicellulose, pectins, and glucoprotein containing many negative charges (generated by carboxylic groups) that act as cation binding sites and exchangers and as anion repellers. Di- and polyvalent cations (the form of many heavy metal and radionuclide contaminants) are preferentially attracted to, and bound on, these cation exchange sites within the root cortex cell walls (Negri *et al*., 1996). Some researchers believe that plants for

phytoremediation should accumulate metals only in the roots (Dushenkov *et al*., 1995; Salt *et al*., 1995; Flathman and Lanza, 1998). Dushenkov *et al*. (1995) explained that the translocation of metals to shoots may decrease the efficiency of rhizofiltration by increasing the amount of contaminated phytomass which will need disposal. Phytoremediation differs from other pollutant treatment systems, which may have only one specific pollutant removal mechanism, in that several strategies, such as planned periodic harvests or natural dieback of aerial shoot of plant biomass to eliminate the accumulated metals, can be employed (Louis and Isebrands, 2005). Then when harvest comes after the plants have performed their phytoremediation role, the potential exists for the use of the harvested phytomass for further extraction of metals from the harvested material. Previous studies on *T. domingensis* proved the qualification of the species biomass as metals biosorbent (Abdel-Ghani *et al*., 2009a; b).

CONCLUSION

The concentrations of Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} in wastewater ponds in the study area exceeded the upper limits indicated by the Egyptian environmental regulations. The native aquatic plant species *T. domingensis* accumulates high concentrations of Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} in their roots. There were significantly positive relationships between the concentrations of Al^{3+}, Fe^{3+}, Zn^{2+} and Pb^{2+} in the *T. domingensis* roots and those in water. *T. domingensis L.* has the potential to be used in phytoremediation purposes to remove metal pollutants from contaminated wastewaters.

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