*Terrestrial and Aquatic Environmental Toxicology* ***©2007 Global Science Books***

# Heavy Metals in Soils and Plants from Various Metal-Contaminated Sites in Egypt

**Reda A. Abou-Shanab[1*] • Hanan A. Ghozlan[2] • Khaled M. Ghanem[2] • Hassan A. Moawad[3]**

[1] Environmental Biotechnology Department, Genetic Engineering Institute, Mubarak City for Scientific Research and Technology Applications, Borg El Arab, Alexandria, Egypt
[2] Botany Department, Faculty of Science, University of Alexandria, Alexandria, Egypt
[3] Agricultural Microbiology Department, National Research Center, Cairo, Egypt
***Corresponding author*: * redaabushanab@yahoo.com**

## ABSTRACT

A field-survey of higher plants growing in metal-contaminated sites in Egypt was conducted to examine the scope and magnitude of metal/soil contamination in Egypt, and to determine the existence of Egyptian plant flora that accumulate large concentrations of metals in their shoots which might be useful in phytoremediation. Eight sites were investigated in northwestern Egypt, the Nile Delta region, and southeastern parts of the country. Soil samples and 61 plant species were collected from these sites and were analysed for Cd, Cr, Co, Cu, Fe, Ni, Pb, and Zn. Each soil exhibited a high concentration of one or more metals. Maximum Cr and Ni contents were observed in *Diplachne fusca* (674 mg Cr kg$^{-1}$ and 253 mg Ni kg$^{-1}$ DM). The highest Cu concentration (174 mg kg$^{-1}$) was observed in *Urtica urens*. The concentration of Pb in *Conyza discoridies* (508 mg kg$^{-1}$) was 11 times greater than the total Pb concentration in soil. *Cichorium endivia* contained 938 mg Zn kg$^{-1}$ that was approximately two-fold the maximum value of Zn in the uncontaminated plant samples.

**Keywords:** *Conyza discoridies*; *Diplachne fusca*; hyperaccumulator; industrial sites; phytoremediation

## INTRODUCTION

Soils may become polluted with high concentrations of heavy metals, as a result of their proximity to mineral outcrops or ore bodies, or anthropogenically as a result of industrial activities. Metalliferous mining and processing, including waste dumping, usually results in the most severe cases of heavy metal pollution. Deposition of air-borne metal particulates generated by smelting activities represents a similar potential hazard for the transfer of metal pollutants (Abdel-Aal *et al*. 1988; Shahin *et al*. 1988; Baker *et al*. 1995; Rashed *et al*. 1995; Bååth *et al*. 1998; Wenzel and Jockwer 1999; Kabata-Pendias and Pendias 2001).

Heavy metal contamination of groundwater and soil is in need of effective and affordable remediation technologies. Unlike organic pollutants, metals cannot be degraded to harmless products, such as carbon dioxide, but instead persist indefinitely in the environment complicating their remediation (Burd *et al*. 1998; Lasat 2002). Present technologies rely upon metal extraction or immobilization processes, although both are expensive and result in the removal of all biological activity in the soil during decontamination. Other, metal-extraction processes use stringent physicochemical agents that can dramatically inhibit soil fertility with subsequent negative impacts on the ecosystem (Cunningham *et al*. 1995; Saxena *et al*. 1999; Wenzel *et al*. 1999).

Phytoremediation, a low-cost solution to soil contamination compared with traditional removal and/or disposal techniques, has been proposed to remove excess metals from soils (Chaney 1983). This technology was developed after the identification of certain plants, metal "hyperaccumulators", that are able to accumulate and tolerate extremely high concentrations of metals in their shoots (Chaney 1983; Baker *et al*. 2000). Baker and Brooks (1989) defined hyperaccumulator plant species as plants which accumulate >1000 mg kg$^{-1}$ of Cu, Co, Cr, Ni or Pb, or >10,000 mg kg$^{-1}$ of Mn or Zn. Hyperaccumulation of metals has been found in temperate as well as in tropical regions throughout the plant kingdom, but is generally restricted to endemic species growing on mineralised soil and related rock types (Baker and Brooks 1989). Hyperaccumulator plants represent a potential for remediation of soils polluted by heavy metals (Baker *et al*. 1994; Wenzel *et al*. 1999; Abou-Shanab *et al*. 2003). Presently, only a few hundred-plant species have been identified as hyperaccumulators. To make phytoremediation environmentally practical, hyperaccumulator adapted to diverse climates and soils must be discovered. The aim of the present work was therefore study

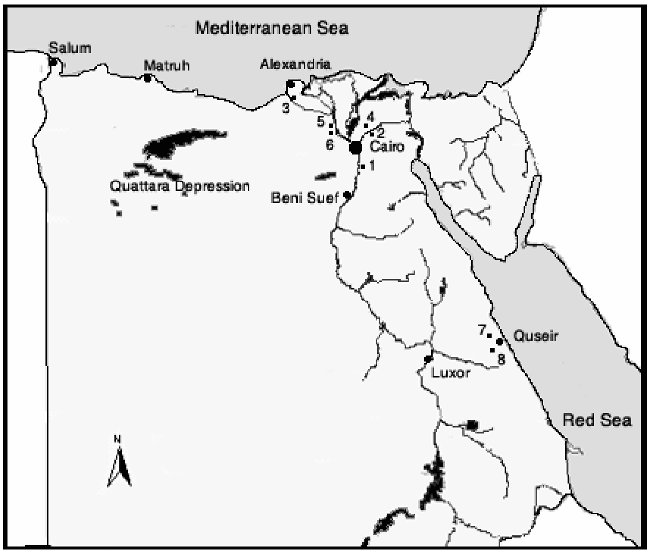

**Fig. 1 Map of Egypt showing the various sampling sites.** 1, Makhar El-Saeel; 2, Bahteem drain; 3, Lake Mariout; 4, 10th of Ramadan City; 5, El-Kom El-Ahmar; 6, Sekaeel; 7, Umm-Gheig; 8, Zug El-Bohar.

Received: 5 November, 2006. Accepted: 27 February, 2007.

plants that grow in high metal soils of Egypt. This area of the world has yet to be extensively explored for plants able to accumulate high concentrations of metals.

## MATERIALS AND METHODS

### Sites investigated

Soil and plant samples were collected from sites chosen for their industrial activities and/or historical backgrounds. Sampling was conducted at eight locations representing four industrial and municipal metal contaminated sites (Makhar El Saeel, Bahteem Drain, Lake Mariut and 10th Ramadan City oxidation ponds); two agricultural sites exposed to smelter emissions (El-Kom El-Ahmar and Sekaeel), and two mining sites (Umm-Gheig and Zug El-Bohar) (**Fig. 1**).

### Soil sampling and preparation

Five soil samples were collected from each location, generally around the roots of collected plant species. Soil samples were mixed in a large container, air-dried and sieved through a 4 mm stainless steel sieve to remove rocks and un-decomposed organic materials. Soil mechanical analysis was carried out by the pipette method according to Black *et al*. (1982). The percentage of water-holding capacity was determined according to Alef and Nannipieri (1995). Soil pH was electrometrically determined after mixing 1 g of soil in 2.5 ml water for about 5 min, allowed ionic exchange to reach equilibrium prior reading (Black *et al*. 1982). Organic carbon content was measured by the rapid titration method (Nelson and Sommers 1986). Cation exchange capacity was determined using sodium acetate for saturation and ammonium acetate for displacement as exchangeable base (Thomes 1982). Extractable metals were measured by shaking 10 g air-dried soil for two hr in 30 ml 5 mM DTPA (diethylene triaminopenta acetic acid), 10 mM $CaCl_2.2H_2O$, and 100 mM TEA (triethanolamine) buffered at pH 7.3 (Lindsay and Norvell 1978). Samples were filtered and acidified with $HNO_3$ before analysis. Total metals in soil were determined by digesting 500 mg of soil in a mixture of concentrated $HNO_3/HClO_4$ (10:7, v/v) (Huang *et al*. 1997). Total and extractable metals were determined using flame atomic absorption spectrophotometry (Perkin Elmer 2380).

### Plant sampling, identification and preparation

One plant for each species was randomly collected. The collected plant species were identified according to Täkholm (1974) and Boulos (1995) using herbarium plant reference species held in the Faculty of Science, University of Alexandria and the National Research Center (Egypt). A whole plant was excavated and divided into roots and shoots and both carefully washed several times in distilled water. Washed plant material was dried at 70°C for 72 h and ground to pass a 2-mm mesh sieve. 400 mg dry plant tissue were digested in a mixture of $HNO_3/HClO_4$ (10:7, v/v) (Huang *et al*. 1997) and then brought to a constant volume with deionized water. Digests were analysed for Cd, Cr, Co, Cu, Ni, Pb, Zn, and Fe by flame atomic absorption spectrophotometry (Perkin Elmer 2380).

### Statistical analysis

Statistical analyses were conducted using SAS version 8.2 (SAS Institute Inc., 1999-2001). Correlations between plant metal concentrations and soil total and extractable metal concentrations were estimated by the Pearson product-moment correlation coefficient.

## RESULTS AND DISCUSSION

### Soils

Physicochemical characteristics of soils are shown in **Table 1.** The pH of all soil samples was alkaline. Soil pH is one of the most influential parameters controlling the conversion of metals from immobile solid-phase to more mobile and/or bioavailable solution-phase. Egyptian soil pHs are generally in the alkaline range (7.7-8.3). The solubility of heavy metals is generally greater in the pH range of normal agricultural soils (approximately pH 5.0 to 7.0) (Sanders 1983; Alloway 1995). Organic matter contents varied between 0.8% and 4.1%, and cation exchange capacity in most of the samples ranged from 13 to 26 meq 100 $g^{-1}$ soil. Lake Mariout, El-Kom El-Ahmar, and Sekaeel had a higher CEC, which ranged between 92 and 109 meq $100g^{-1}$ soil. The CEC of soil is of major importance in determining the extent to which heavy metals are adsorbed by the solid phase constituents and hence, the extent of their solubility. In general, soils with high CECs can adsorb larger amounts of heavy metals than soils with low CEC. Soil organic matter also has high specific surface area; consequently the majority of CEC in soil is from organic matter. All soils were found to be granular with balanced sandy clay loam, to silt to loamy sand texture.

Total metal content is important because it determines the size of the metal pool in the soil and thus available for

**Table 1** Physico-chemical properties of soil samples.

| Site | Texture | Sand | Silt | Clay | OM* | *CEC*** | pH |
|---|---|---|---|---|---|---|---|
| | | | | % | | meq $100g^{-1}$ | |
| Makhar El-Saeel | Sandy loam | 67 | 20 | 13 | 1.2 | 13 | 8.2 |
| Bahteem | Loamy sand | 76 | 18 | 6 | 2.6 | 26 | 7.7 |
| Lake Mariout | Silt loam | 14 | 62 | 24 | 3.6 | 109 | 8.1 |
| 10th of Ramadan City | Sandy loam | 80 | 5 | 15 | 1.8 | 13 | 7.9 |
| El-Kom, El-Ahmar | Loam | 39 | 41 | 20 | 3.2 | 108 | 8.3 |
| Sekaeel | Loam | 50 | 37 | 13 | 3.1 | 92 | 8.1 |
| Umm-Gheig | Sandy loam | 77 | 11 | 12 | 0.8 | 13 | 8.2 |
| Zug El-Bohar | Sandy loam | 72 | 10 | 18 | 1.1 | 15 | 8.3 |

*OM = Organic matter; **Cation exchange capacity.

**Table 2** Total (*T*) and DTPA-extractable (*E*) concentration of heavy metals.

| Site | Cd | | Cr | | Co | | Cu | | Ni | | Pb | | Zn | | Fe | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *T* | *E* | *T* | *E* | *T* | *E* | *T* | *E* | *T* | *E* | *T* | *E* | *T* | *E* | *T* | *E* |
| | | | | | | | | | mg $kg^{-1}$ dry soil | | | | | | | |
| Makhar El-Saeel | 3 | <DL | 50 | 0.9 | 39 | 0.1 | 21 | 1.3 | 79 | 0.2 | 46 | 19 | 2202 | 126 | 49491 | 21 |
| Bahteem | 0.9 | 0.1 | 39 | 0.1 | 7 | 0.1 | 96 | 20 | 37 | 1.6 | 430 | 76 | 72 | 8.1 | 2142 | 36 |
| Lake Mariout | 4 | 0.2 | 67 | <DL | 31 | <DL | 40 | 8 | 56 | <DL | 30 | 1.5 | 66 | <DL | 3870 | 50 |
| 10th of Ramadan City | 2 | 0.1 | 19 | 0.03 | 6 | 0.1 | 8 | 0.9 | 12 | 0.5 | 5 | 1 | 20 | 1.8 | 3477 | 15 |
| El-Kom El-Ahmar | 3 | 0.2 | 35 | 0.04 | 16 | 0.1 | 279 | 10.4 | 46 | 0.73 | 54 | 3.3 | 202 | 9.1 | 5350 | 5 |
| Sekaeel | 0.9 | 0.1 | 43 | 0.01 | 17 | 0.2 | 136 | 26.2 | 55 | 1.2 | 61 | 7.5 | 115 | 10.1 | 5900 | 5 |
| Umm-Gheig | 14 | <DL | 33 | 0.9 | 30 | 0.2 | 33 | 0.9 | 72 | 0.3 | 3504 | 259 | 5631 | 64 | 2498 | 5 |
| Zug El-Bohar | 2 | <DL | 76 | 0.4 | 21 | 0.7 | 22 | 0.4 | 34 | 0.2 | 4055 | 605 | 14822 | 29 | 5789 | 5 |

DTPA= diethylene tri-aminopenta acetic acid. <DL= below detection limit. ND= not determined.

metal uptake (Ibekwe *et al.* 1995). Therefore, soil samples were analyzed for total and DTPA extractable concentrations of Cd, Cr, Co, Cu, Ni, Pb, Zn, and Fe. Results (**Table 2**) showed that each site exhibited a high concentration of one or more metals. Variation was also recorded in the extractable metal content, i.e. biologically available metals in comparison to the total metal content in the same soil. This can be attributed to the behavior of trace metals in soils that depends not only on the level of contamination, as expressed by the total content, but also on the form and origin of the metal and the properties of the soils themselves (Tessier and Campbell 1988; Evans 1989; Chlopecka *et al.* 1996). Total Cd content in soils varied between 0.9 and 14 mg kg$^{-1}$ dry soil and the highest value was recorded in the Umm-Gheig mining site. The highest DTPA extractable Cd was found at Lake Mariout and El-Kom El-Ahmar with 0.2 mg

**Table 3** Heavy metal concentrations in plants collected from different sites.

| **Location** | **Family** | **Species** | **Plant part** | **Cd** | **Cr** | **Co** | **Cu** | **Ni** | **Pb** | **Zn** | **Fe** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **mg kg$^{-1}$ dry wt** | | | | | | | |
| Makhar El-Saeel | Asteraceae | *Conyza linifolia* | Flowering shoots | 4 | <DL | 17 | 24 | <DL | 373 | 623 | 5000 |
| | Asteraceae | *Conyza discoridies* | Flowering shoots | 2 | 20 | 19 | 20 | <DL | 508 | 113 | 8000 |
| | Asteraceae | *Eclipta alba* | Shoots | 4 | <DL | 5 | 14 | 8 | 5 | 54 | <DL |
| | Chenopodiaceae | *Chenopodium album* | Shoots | 0.8 | <DL | 16 | 1.3 | <DL | 10 | 48 | 363 |
| | Chenopodiaceae | *Kochia indica* | Shoots | 5 | 91 | 9 | 14 | <DL | 20 | 53 | 2000 |
| | Cyperaceae | *Cyperus articulatus* | Flowering shoots | 3 | <DL | 12 | 23 | 5 | 195 | 773 | 3000 |
| | Cyperaceae | *Cyperus laevigatus* | Flowering shoots | 3 | <DL | 4 | 5 | 217 | 153 | 169 | 2000 |
| | Euphorbiaceae | *Ricinus communis* | Leaves | 4 | <DL | 12 | 10 | <DL | 3 | 43 | 338 |
| | Poaceae | *Diplachne fusca* | Flowering shoots | 2 | 674 | 13 | 15 | 253 | 410 | 212 | 13000 |
| | Poaceae | *Phragmites australis* | Flowering shoots | <DL | <DL | 7 | 16 | <DL | 218 | 200 | 3000 |
| | Polygonaceae | *Polygonum salicifolium* | Shoots | 0.3 | <DL | 12 | <DL | <DL | 70 | 132 | 200 |
| | Portulacaceae | *Portulaca oleracea* | Shoots | <DL | 29 | 6 | 21 | 40 | 20 | 82 | 6000 |
| | Solanaceae | *Solanum nigrum* | Shoots | 2 | <DL | 16 | 54 | <DL | 215 | 165 | 7000 |
| Bahteem | Cyperaceae | *Cyperus articulatus* | Flowering shoots | 5 | 9 | 16 | 10 | 43 | 24 | 11 | 301 |
| | Cyperaceae | *Cyperus alopecuroides* | Flowering shoots | 1 | 2 | 15 | 13 | 15 | 19 | 15 | 489 |
| | Poaceae | *Phragmites australis* | Flowering shoots | 4 | 9 | 8 | 4 | 31 | 5 | 8 | 208 |
| Lake Mariout | Asteraceae | *Conyza discoridies* | Flowering shoots | 0.3 | 1 | 0.2 | 10 | 3 | 2 | 25 | 360 |
| | Asteraceae | *Inula crithmoides* | Shoots | 5 | 30 | 13 | 6 | 47 | 14 | 16 | 4000 |
| | Asclepiadaceae | *Cynanchum acutum* | Shoots | 8 | 7 | 5 | 10 | 16 | 53 | 53 | 325 |
| | Chenopodiaceae | *Chenopodium sp.* | Shoots | <DL | 6 | 7 | 9 | 21 | 3 | 40 | 495 |
| | Chenopodiaceae | *Anabasis articulata* | Shoots | 2 | 5 | 11 | 10 | 7 | 15 | 29 | 385 |
| | Juncaceae | *Juncus acutus* | Shoots | 0.6 | 13 | 3 | 10 | 11 | 8 | 33 | 183 |
| | Lemnaceae | *Lemna gibba* | Whole | 4 | 30 | 21 | 11 | 42 | 3 | 52 | 3000 |
| | Poaceae | *Phragmites australis* | Flowering shoots | 3 | 98 | 3 | 10 | 15 | 2 | 17 | 897 |
| | Polygonaceae | *Polygonum salicifolium* | Shoots | 0.2 | 55 | 7 | 5 | 18 | 8 | 23 | 888 |
| | Ponederiaceae | *Eichornia crassipes* | Shoots | <DL | 63 | 5 | 11 | 29 | <DL | 25 | 552 |
| | Tamaricaceae | *Tamarix aphylla* | Shoots | 1 | 78 | 7 | 12 | 10 | <DL | 52 | 1 |
| | Typhaceae | *Typha latifolia* | Flowering shoots | 1 | 5 | 2 | 8 | 8 | 1 | 13 | 228 |
| 10th of Ramadan | Asteraceae | *Cichorium endivia* | Shoots | 7 | 12 | 15 | 10 | 33 | 6 | 938 | 3000 |
| | Cyperaceae | *Cyperus laevigatus* | Flowering shoots | 2 | 5 | 2 | 20 | 14 | 23 | 23 | 1000 |
| | Plantaginaceae | *Plantago major* | Flowering shoots | 2 | 7 | 5 | 17 | 14 | 31 | 6 | 1000 |
| | Poaceae | *Diplachne fusca* | Flowering shoots | 6 | 13 | 4 | 22 | 22 | 36 | 47 | 1400 |
| | Poaceae | *Pharagmites australis* | Flowering shoots | 2 | 3 | 1 | 8 | 5 | 24 | 14 | 401 |
| | Tamaricaceae | *Tamarix nilotica* | Shoots | 3 | 10 | 6 | 16 | 17 | 8 | 19 | 1200 |
| | Typhaceae | *Typha elephantina* | Flowering shoots | 2 | 12 | 12 | 27 | 29 | 30 | 20 | 3200 |
| Lake Mariout | Asteraceae | *Conyza discoridies* | Flowering shoots | 0.3 | 1 | 0.2 | 10 | 3 | 2 | 25 | 360 |
| El-Kom El-Ahmar | Asteraceae | *Sonchus oleraceus* | Flowering shoot | 3 | 5 | 8 | 42 | 51 | 16 | 47 | 4000 |
| | Brassicaceae | *Brassica sp.* | Shoots | 3 | 3 | 8 | 19 | 52 | 50 | 18 | 995 |
| | Fabaceae | *Trifolium alexandrinum* | Flowering shoot | 2 | 0.4 | 8 | 20 | 35 | 15 | 27 | 3000 |
| | Poaceae | *Triticum aestivum* | Flowering shoot | 3 | 7 | 6 | 14 | 39 | 3 | 28 | 913 |
| Sekaeel | Asteraceae | *Cichorium endivia* | Shoots | 6 | 13 | 6 | 72 | 26 | 20 | 43 | 524 |
| | Chenopodiaceae | *Chenopodium murale* | Shoots | 2 | 20 | 12 | 46 | 31 | 19 | 32 | 963 |
| | Cyperaceae | *Cyperus rotundus* | Flowering shoot | 4 | 18 | 3 | 24 | 38 | 5 | 24 | 314 |
| | Euphorbiaceae | *Ricinus communis* | Leaves | 4 | 9 | 3 | 43 | 36 | 14 | 49 | 270 |
| | Fabaceae | *Trifolium alexandrinum* | Flowering shoot | 4 | 9 | 6 | 50 | 42 | 19 | 108 | 2000 |
| | Malvaceae | *Malva parviflora* | Shoots | 3 | 10 | 7 | 71 | 56 | 11 | 146 | 851 |
| | Urticaceae | *Urtica urens* | Shoots | 6 | 8 | 10 | 174 | 57 | 43 | 364 | 1000 |
| Umm-Gheig | Asteraceae | *Conyza aegyptiaca* | Flowering shoots | 7 | 5 | 4 | 10 | <DL | 40 | 106 | 2000 |
| | Boraginaceae | *Alkanna tinctoria* | Shoots | 5 | 9 | 5 | 7 | 10 | 255 | 734 | 5000 |
| | Boraginaceae | *Anchusa aegyptiaca* | Shoots | 6 | <DL | 3 | 11 | 16 | 62 | 109 | 347 |
| | Cruciferae | *Zilla spinosa* | Shoots | 9 | 0.2 | 8 | 17 | 7 | 53 | 259 | 753 |
| | Fabaceae | *Crotolaria aegyptiaca* | Flowering shoots | 4 | <DL | <DL | 12 | 8 | 26 | 71 | 169 |
| | Resedaceae | *Reseda pruinosa* | Shoots | 5 | <DL | 6 | 9 | 3 | 12 | 47 | 267 |
| | Urticaceae | *Forsskalea tenacissima* | Shoots | 7 | 228 | 10 | 8 | 26 | 94 | 334 | 2000 |
| | Zygophyllaceae | *Zygophyllum simplex* | *Flowering shoots* | 10 | 2 | 5 | 13 | 12 | 151 | 472 | 2000 |
| | Zygophyllaceae | *Zygophyllum coccineum* | *Flowering shoots* | 14 | <DL | 13 | 7 | 21 | 93 | 219 | 356 |
| Zug El-Bohar | Asteraceae | *Conyza aegyptiaca* | Flowering shoots | <DL | <DL | 0.7 | 19 | 4 | 51 | 79 | 1000 |
| | Boraginaceae | *Anchusa aegyptiaca* | Shoots | 2 | 376 | 10 | 16 | 18 | 80 | 205 | 614 |
| | Fabaceae | *Crotalaria aegyptiaca* | Flowering shoots | 3 | 4 | 6 | 7 | <DL | 22 | 79 | 408 |
| | Resedaceae | *Reseda pruinosa* | Shoots | 1 | 4 | 13 | 5 | 10 | 44 | 127 | 395 |
| | Urticaceae | *Forsskalea tenacissima* | Shoots | 2 | 26 | 11 | 12 | 31 | 62 | 102 | 4000 |
| | Zygophyllaceae | *Zygophyllum coccineum* | Flowering shoots | 2 | <DL | 4 | 8 | <DL | 126 | 293 | 128 |

<DL= below detection limit

kg$^{-1}$. Chromium concentration in soils was also elevated as a result of both natural and anthropogenic sources and varied from 19 to 76 mg kg$^{-1}$. The highest concentration was found at the Zug El-Bohar mining site. The concentration of available Cr was very low in most of the soil samples, approximately 0.9 mg kg$^{-1}$ at both Makhar El-Saeel and Umm-Gheig. Copper concentration in soils was constantly less than 96 mg kg$^{-1}$, except for El-Kom El-Ahmar and Sekaeel, where the total Cu concentrations were 279 and 136 mg kg$^{-1}$, respectively. DTPA-extractable Cu was the highest at the Sekaeel smelter site as a result of long-term deposition of Cu dust. Soil from Makhar El-Saeel contained higher concentrations of total Fe (49491 mg kg$^{-1}$) compared to other sites as a result of industrial activities and long-term deposition of iron dust, while Lake Mariout was distinguished by high available Fe (50 mg kg$^{-1}$ dry soil). High levels in the parent material and historical Pb and Zn mining activities led to anomalous large concentrations of these metals in Umm-Gheig and Zug El-Bohar mining sites with 3504, 4055 mg Pb kg$^{-1}$ and 5631, 14822 mg Zn kg$^{-1}$, respectively. Available Pb and Zn were also much higher at both sites and at Makhar El-Saeel. The concentrations of these metals were high compared to the values generally observed in agricultural soils and considered to be toxic according to Swaine (1955).

## Plants

Sixty-one plant species, belonging to 34 genera and representing 22 families, were collected from the sites of investtigation. Families, names of plant species, and heavy metal concentrations in different plant parts are summarized in **Tables 3**, **4**, and **5**. The reported normal range of metal concentrations in plants are 0.03-15 mg Cr kg$^{-1}$; 4-15 mg Cu kg$^{-1}$; 0.1-10 mg Pb kg$^{-1}$; 0.02-5 mg Ni kg$^{-1}$; 0.05-0.5 mg Co kg$^{-1}$; 0.2-0.8 mg Cd kg$^{-1}$; and 8-400 mg Zn kg$^{-1}$ (Swaine 1955; Allaway 1968; Reeves *et al.* 1995; Kabata-Pendias and Pendias 2001).

Results show that Cd in plants was relatively high and ranged from 0.2 to 6 mg kg$^{-1}$. The highest Cd concentrations (9-14 mg kg$^{-1}$) were recorded in plants collected from the Umm Gheig mining site and maximum Cd content of 14 mg kg$^{-1}$ was observed in flowering shoots of *Zygophyllum coccineum* followed by *Z. simplex* (10 mg kg$^{-1}$). The ratio of plant/soil metal concentration reached 2 for Cd in *Cynanchum acutum* collected from the Lake Mariout site.

Chromium concentrations in plants ranged from 0.4 to 20 mg kg$^{-1}$ for most plant species studied. Plants collected from Lake Mariout contained relatively higher amounts of Cr (30-98 mg kg$^{-1}$). However, the maximum Cr content (674 mg kg$^{-1}$) was observed in flowering shoots of *Diplachne fusca* collected from Makhar El-Saeel, followed by *Anchusa aegyptiaca* (376 mg kg$^{-1}$) shoots collected from Zug El-Bohar, and in *Forsskalea tenacissima* (228 mg kg$^{-1}$) shoots collected from Umm-Gheig. Chromium concentrations in flowering shoots of *D. fusca* were about 13-fold the total Cr concentration in soil.

Cobalt concentrations in plants varied from 0.2 to 21 mg kg$^{-1}$. Higher levels of Co (21 mg Co kg$^{-1}$) were observed in *Lemna gibba* collected from Lake Mariout and was about 70% of the total Co concentration in soil.

Wide ranges of Cu concentrations were observed among the plants collected at different sites (1.3 to 174 mg kg$^{-1}$). *Urtica urens*, collected from the Sekaeel agricultural area exposed to copper and iron smelter dust showed the highest Cu concentration (174 mg Cu kg$^{-1}$). All other plants collected from Sakaeel were relatively high in their Cu content followed by plants collected from El-Kom El-Ahmar.

**Table 4** Pearson correlation coefficients between plant biomass metal concentration and soil total metal concentrations Prob > |r| under H0: Rho=0

| | Plant Cd | Plant Cr | Plant Co | Plant Cu | Plant Fe | Plant Ni | Plant Pb | Plant Zn |
|---|---|---|---|---|---|---|---|---|
| Soil Cd | 0.93*** | 0.60*** | -0.05 | -0.40** | -0.20 | -0.38** | 0.28* | 0.23 |
| | 33[†] | 49 | 49 | 61 | 61 | 49 | 61 | 49 |
| Soil Cr | 0.73*** | 0.25 | 0.75*** | -0.02 | 0.46*** | -0.26 | 0.35** | 0.30* |
| | 33 | 49 | 49 | 61 | 61 | 49 | 61 | 49 |
| Soil Co | 0.81*** | 0.92*** | -0.07 | -0.38** | 0.28* | -0.63*** | -0.03 | 0.95*** |
| | 33 | 49 | 49 | 61 | 61 | 49 | 61 | 49 |
| Soil Cu | -0.04 | -0.13 | -0.05 | 0.35** | -0.09 | 0.10 | -0.23 | -0.21 |
| | 56 | 59 | 60 | 60 | 60 | 51 | 59 | 61 |
| Soil Fe | -0.20 | 0.15 | 0.34** | -0.01 | 0.51*** | 0.47*** | 0.53*** | 0.18 |
| | 56 | 59 | 60 | 60 | 60 | 51 | 59 | 61 |
| Soil Ni | 0.20 | 0.10 | 0.19 | 0.01 | 0.29* | 0.22 | 0.40** | 0.17 |
| | 56 | 59 | 60 | 60 | 60 | 51 | 59 | 61 |
| Soil Pb | 0.36** | 0.09 | -0.12 | -0.22 | -0.14 | -0.22 | 0.06 | 0.22 |
| | 56 | 59 | 60 | 60 | 60 | 51 | 59 | 61 |
| Soil Zn | 0.07 | 0.16 | -0.03 | -0.20 | -0.03 | -0.11 | 0.14 | 0.18 |
| | 56 | 59 | 60 | 60 | 60 | 51 | 59 | 61 |

[†] Number of observations *, **, and *** indicate the significance at the 0.05, 0.01, and 0.001 probability levels, respectively.

**Table 5** Pearson correlation coefficients between plant biomass metal concentration and soil EDTA extractable metal concentrations Prob > |r| under H0: Rho=0

| | Plant Cd | Plant Cr | Plant Co | Plant Cu | Plant Fe | Plant Ni | Plant Pb | Plant Zn |
|---|---|---|---|---|---|---|---|---|
| Soil Cd | -0.29 | 0.34 | -0.06 | -0.38* | 0.09 | -0.15 | -0.22 | -0.24 |
| | 31[†] | 33 | 33 | 33 | 33 | 33 | 31 | 33 |
| Soil Cr | 0.25 | 0.16 | 0.22 | -0.35* | 0.33* | 0.11 | 0.49*** | 0.29* |
| | 46 | 47 | 48 | 48 | 48 | 39 | 49 | 49 |
| Soil Co | -0.12 | 0.13 | -0.15 | -0.09 | -0.21 | -0.18 | -0.08 | 0.00 |
| | 46 | 47 | 48 | 48 | 48 | 39 | 49 | 49 |
| Soil Cu | -0.04 | -0.13 | -0.04 | 0.56*** | -0.25 | 0.06 | -0.31* | -0.24 |
| | 56 | 59 | 60 | 60 | 60 | 51 | 59 | 61 |
| Soil Fe | -0.31* | 0.00 | 0.07 | -0.29* | -0.07 | -0.06 | -0.11 | -0.26* |
| | 56 | 59 | 60 | 60 | 60 | 51 | 59 | 61 |
| Soil Ni | -0.03 | -0.17 | -0.01 | 0.42*** | -0.31* | -0.02 | -0.38** | -0.27 |
| | 46 | 47 | 48 | 48 | 48 | 39 | 49 | 49 |
| Soil Pb | 0.13 | 0.13 | -0.07 | -0.20 | -0.13 | -0.18 | 0.05 | 0.14 |
| | 56 | 59 | 60 | 60 | 60 | 51 | 59 | 61 |
| Soil Zn | 0.00 | 0.17 | 0.33* | -0.22 | 0.46** | 0.31 | 0.55*** | 0.23 |
| | 46 | 47 | 48 | 48 | 48 | 39 | 49 | 49 |

[†] Number of observations *, **, and *** indicate the significance at the 0.05, 0.01, and 0.001 probability levels, respectively.

Lead concentrations in plant shoots varied from 1 to 508 mg kg$^{-1}$. *Conyza discoridies*, collected from Makhar El-Saeel, showed higher Pb uptake compared with other plant species. The concentration of Pb in *C. discoridies* shoots was about 11-fold the concentration in soil. Most plants collected from the same site were higher in their Pb content although Makhar El-Saeel was not as high as other areas in Pb content. *Alkanna tinctoria* contained the highest Pb content (225 mg kg$^{-1}$) among the plants collected from Umm-Gheig.

Zinc content in plants was low in most species except for *Cichorium endivia* specimens collected from 10th of Ramadan City (938 mg kg$^{-1}$). Plant concentrations were about 47-fold higher than Zn concentration in soil. *Cyprus articulatus* and *Conyza linifolia* collected from Makhar El-Saeel contained relatively high Zn (773 and 623 mg kg$^{-1}$), while *A. tinctoria* collected from Umm-Gheig contained 732 mg kg$^{-1}$.

Iron concentrations were high and varied from the lowest concentration 1 mg kg$^{-1}$ to the highest concentrations 13,000 mg Fe kg$^{-1}$ were observed in *Tamarix aphylla* and *D. fusca*, were collected from Lake Mariout and Makhar El-Saeel, respectively. Iron concentration in *D. fusca* was about 3-fold lower than total Fe in soil. Generally, plants collected from Makhar El-Saeel, especially belonging to family Asteraceae and Poaceae were higher in Fe content (3000-8000 mg kg$^{-1}$).

Nickel concentrations in plant tissue varied from 3 to 253 mg kg$^{-1}$. Plants from Makhar El-Saeel had the highest Ni concentrations in shoots of *D. fusca* at 253 mg kg$^{-1}$ and *C. laevigatus* at 217 mg kg$^{-1}$. The nickel content in *D. fusca* was three times higher than the total Ni concentration in soils.

Correlations between plant biomass metal concentrations and soil metal concentrations cross all sites revealed that plant Cd, Cu, and Fe were each significant with soil total Cd, Cu, and Fe, respectively. There was no correlation between plant Cr, Co, Ni, Pb, and Zn and corresponding soil total metal concentrations (**Table 4**). A lack of correlation was probably due to the fact that many factors control metal solubility. Total metal concentration is regarded as a poor indicator of metal phytoavailability. For hyperaccumulators, due to their unusual ability to extract metals from soil, the link between soil metal content and biomass metal content is also usually weak. It interesting to note that there is an extreme high correlation coefficient ($r = 0.93$, $P < 0.001$) between soil total Cd and plant Cd. This is consistent with literature that soil Cd in present mostly in labile pools (Baker *et al.* 1994). Except for plant Cu that was significantly correlated with soil EDTA extractable Cu, all other plant metal concentrations were not correlated with corresponding soil EDTA extractable metals (**Table 5**). This suggests that EDTA extractable metal in a poor indication of metal phytoavailability.

Hyperaccumulation is defined as uptake and sequestration of exceptionally high concentrations of an element in the above ground parts of a plant under field conditions. Baker and Brooks (1989) argue for the recognition of standard criteria for hyperaccumulation at concentrations of 10,000 mg kg$^{-1}$ for Mn or Zn; 1,000 mg kg$^{-1}$ for Co, Cr, Cu, Pb or Ni; and 100 mg kg$^{-1}$ for Cd. The results obtained from 61 plant species collected in this study indicated that there were no Cr, Cu, Pb, Ni, Co, Cd, and/or Zn hyperaccumulators according to Brooks (1983), Baker and Brooks (1989), Reeves *et al.* (1995), and Baker *et al.* (2000). However most hyperaccumulators grow very slowly and have small biomass (Cunningham *et al.* 1995). Our observations that *D. fusca*, *C. discorides*, *C. endivia*, *C. articulatus*, and *C. linifolia* produce large biomass and accumulate moderate concentrations of metals under alkaline conditions; may be useful candidate for future study of phytoremediation.

## CONCLUSIONS

Phytoremediation is an emerging technology that is potentially effective and applicable to a number of different contaminants and site conditions. Unfortunately, this technology has yet to be adapted to desert-type conditions. Most past work has focused on temperate regions of the world with less emphasis on tropical areas. No “true” hyperaccumulator was found in Egypt, which was anticipated given that most of the high metal soils where plants were collected were anthropogenically enriched. Land tern exposure is often needed for development of the hyperaccumulative trait. Despite the lack of true hyperaccumulators plants were found with high biomass and moderate metal uptake. These species require further study in order to fully assess their potential utility in phytoremediation.

## REFERENCES

**Abdel-Aal SH, Shahin RR, Abdel-Hamid MA, Abdel-Tawab MM** (1988) Impact of liquid wastes of industrial complex at Helwan on water quality of both Nile and canal streams. *Egyptian Journal of Soil Science* **28**, 421-432

**Abou-Shanab RA, Angle JS, Delorme TA, Chaney RL, van Berkum P, Moawad H, Ghanem K, Ghozlan HA** (2003) Rhizobacterial effects on nickel extraction from soil and uptake by *Alyssum murale*. *New Phytologist* **158**, 219-224

**Alef K, Nannipieri P** (1995) *Methods in Applied Soil Microbiology and Biochemistry*, Academic Press, Harcourt Brace and Company Publishers, London, pp 105-121

**Allaway WH** (1968) Agronomic controls over the environmental cycling of trace elements. *Advances in Agronomy* **20**, 235-274

**Alloway BJ** (1995) Soil processes and the behavior of metals. In: Alloway BJ (Ed) *Heavy Metals in Soils*, Blackwell Academic and Professional Publisher, London, pp 11-37

**Bååth E, Diaz-Ravina M, Frostegard A, Campbell CD** (1998) Effect of metal-rich sludge amendments on the soil microbial community. *Applied and Environmental Microbiology* **64**, 238-245

**Baker AJM, Brooks RR** (1989) Terrestrial higher plants which hyperaccumulate metallic elements. A review of their distribution, ecology and phytochemistry. *Biorecovery* **1**, 81-126

**Baker AJM, Reeves RD, Hajar ASM** (1994) Phytoremediation potential of *T. caerulescens* and *bladder campion* for zinc- and cadmium-contaminated soil. *Journal of Environmental Quality* **23**, 1151-1157

**Baker AJM, McGrath SP, Sidoli CMD, Reeves RD** (1995) The potential for heavy metal decontamination. *Mining and Environmental Management* **3**, 12-14

**Baker AJM, McGrath SP, Reeves RD, Smith JAC** (2000) Metal hyperaccumulator plants: A review of the ecology and physiology of a biological resource for phytoremediation of metal-polluted soils. In: Terry N, Banuelos G (Eds) *Phytoremediation of Contaminated Soil and Water*, Lewis Publishers, London, pp 85-107

**Black BC, Evans DD, White JI, Ensminger LE, Clark FE** (1982) *Methods of Soil Analysis*, American Society of Agronomy Inc. Madison, Wisconsin, USA, pp 539-579

**Boulos L** (1995) *Flora of Egypt Checklist*, Al Hadara Publishing Cairo, Egypt, 237 pp

**Brooks RR** (1983) *Biological Methods of Prospecting for Minerals*, John Wiley and Sons, Inc., NY, pp 15-31

**Burd GI, Dixon DG, Glick BR** (1998) A plant growth-promoting bacterium that decreases nickel toxicity in seedlings. *Applied and Environmental Microbiology* **64**, 3663-3668

**Chaney RL** (1983) Plant uptake of inorganic waste constitutes. In: Parr JE, Marsh PB, Kla JM (Eds) *Land Treatment of Hazardous Wastes*. Noyes Data Corporation, Park Ridge, NJ, pp 50-76

**Chlopecka A, Bacon JR, Wilson MJ, Kay J** (1996) Heavy metals in the environment. *Journal of Environmental Quality* **25**, 69-79

**Cunningham SD, Berti WR, Huang JW** (1995) Phytoremediation of contaminated soils. *Trends in Biotechnology* **13**, 393-397

**Evans LJ** (1989) Chemistry of metal retention by soils. *Environmental Science and Technology* **23**, 1050-1055

**Huang JW, Jianjun C, William RB, Cunningham SD** (1997) Phytoremediation of lead contaminated soils: Role of synthetic chelates in lead phytoremediation. *Environmental Science and Technology* **31**, 800-805

**Ibekwe AM, Angle JS, Chaney RL, van Berkum P** (1995) Sewage sludge and heavy metal effects on nodulation and nitrogen fixation of legumes. *Journal of Environmental Quality* **24**, 1199-1204

**Kabata-Pendias A, Pendias H** (2001) *Trace Elements in Soils and Plants*, CRC Press, Boca Raton, FL, USA, 395 pp

**Lasat MM** (2002) Phytoextraction of toxic metals: a review of biological mechanisms. *Journal of Environmental Quality* **31**, 109-120

**Lindsay WL, Norvell WA** (1978) Development of DTPA soil test of zinc, iron, manganese and copper. *Soil Science Society of American Journal* **42**, 421-428

**Nelson DW, Sommers LE** (1986) Total carbon, organic carbon and organic matter. In: Klute A (Ed) *Methods for Soil Analysis* (Vol 2), American Society of Agronomy, Madison, Wis, pp 539-579

**Rashed F, Abd El-Nabi AO, El-Hemely ME, Khalaf MA** (1995) Background levels of heavy metals in the Nile Delta soils. *Egyptian Journal of Soil Science* **35**, 239-252

**Reeves RD, Baker AJM, Brooks RR** (1995) Abnormal accumulation of trace metals by plants. *Mining Environmental Management* **3**, 4-8

**Sanders JR** (1983) The effects of pH on the total and free ionic concentrations of manganese, zinc, and cobalt in soil solutions. *Journal of Soil Science* **34**, 315-323

**Saxena PK, Krishnaraj S, Dan T, Perras MR, Vettakkorumakankav NN** (1999) Phytoremediation of metal contaminated and polluted soils. In: Prasad MNV, Hagemeyer J (Eds) *Heavy Metal Stress in Plants - From Molecules to Ecosystems*, Springer-Verlag, Heidelberg, pp 305-329

**Shahin RR, Abdel-Aal SI, Abdel-Hamid MA** (1988) Soil contamination with heavy metals and soils produced by industrial activities at Helwan. *Egyptian Journal of Soil Science* **28**, 407-419

**Swaine DJ** (1955) The trace element content of soils. Commonwealth Bureau Soil Science Technical Communication No. 48, CAB, Farnham Royal, Bucks, UK, 157 pp

**Täckholm V** (1974) *Student's Flora of Egypt* (2nd Edn), Cairo University, Egypt, 887 pp

**Tessier A, Campbell PGC** (1988) Partitioning of trace metals in sediments. In: Kramer JR, Allen HE (Eds) *Metal Speciation: Theory, Analysis and Application*, Lewis Publishers, Inc., Chelsea, MI, USA, pp 183-199

**Thomes GW** (1982) Exchangeable Cation In: Page AL (Eds) *Methods of Soil Analysis* (Part 2, Agronomy Monograph 9), American Society of Agronomy, Madison, WI, USA, pp 159-165

**Wenzel WW, Jockwer F** (1999) Accumulation of heavy metals in plants grown on mineralized soils of the Austrian Alps. *Environmental Pollution* **104**, 145-155