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Soil Contamination and Plant Uptake of Heavy Metals at Polluted Sites in China

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2College of Land Resource and Environmental Sciences, Shandong Agricultural University, Shandong Province, P.R. China
3Agricultural and Environmental Science Department, The Queen’s University of Belfast, Belfast, UK

ABSTRACT

We investigated heavy metal contamination in soils and plants at polluted sites in China including some with heavy industries, metal mining, smelting and untreated wastewater irrigation areas. We report our main findings in this paper. The concentrations of heavy metals, including Cd and Zn, in the soils at the investigated sites were above the background levels, and generally exceeded the Government guidelines for metals in soil. The concentrations of metals in plants served to indicate the metal contamination status of the site, and also revealed the abilities of various plant species to take up and accumulate the metals from the soil. Substantial differences in the accumulation of heavy metals were observed among the plant species investigated. Polygonum hydropiper

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growing on contaminated soils in a sewage pond had accumulated 1061 mg kg$^{-1}$ of Zn in its shoots. *Rumex acetosa* L. growing near a smelter had accumulated more than 900 mg kg$^{-1}$ of Zn both in its shoots and roots. Therefore these species have potential for phytoremediation of metal-contaminated sites. Our results indicate the need to elucidate the dynamics of soil metal contamination of plants and the onward movement of metal contaminants into the food chain. Also our results indicate that the consumption of rice grown in paddy soils contaminated with Cd, Cr or Zn may pose a serious risk to human health, because from 24 to 22% of the total metal content in the rice biomass was concentrated in the rice grain. *Platanus acerifolia* growing on heavily contaminated soil accumulated only very low levels of heavy metals, and this mechanism for excluding metal uptake may have value in crop improvement. Sources of metal entering the environmental matrices studied included untreated wastewater, tailings or slurries and dust depositions from metal ore mining, and sewage sludge. Pb, Zn or Cd concentrations declined with the distance from metal smelter in accordance with a good exponential correlation $(R^2 > 0.9)$, and this shows that metal dust deposition is an important contributor to metal contamination of soils.

**Key Words:** Contamination; Crop; Distribution; Heavy metal; Plant/soil; Sources; Phytoremediation.

**INTRODUCTION**

Attention to contamination of soils and plants with heavy metals in China and all over the world is increasing because food safety and human health have become important issues.$^{[1–5]}$ Indeed the toxic effects of metals in the food supply can be serious and even reach disastrous levels. Metal pollutants can easily enter the food chain if heavy metal-contaminated soils are used for production of food crops. For example, the disease known as “itai-itai” and “minamata” was caused by the production of paddy rice on soil contaminated with Cd and Hg in Japan.$^{[6]}$

A considerable number of sites in China have been contaminated with heavy metals by inadvertent spills, atmospheric deposition, inadequate sewage treatment and industrial activities. Yet the need is very great to maintain an extensive and productive agricultural base to feed an increasing population. Therefore the various governments are placing increased emphasis on the cleanup and remediation of contaminated sites, so they can be restored for the production of safe food. Only 0.08 ha of arable land per capita is available in China, or about 1/3 of the world mean.$^{[17]}$

To remediate contaminated soils, a number of measures has been adopted, including leaching, replacing contaminated soils with clean soil, applying soil amendments, etc. Unfortunately, all such measures require huge capital and operational investments, and they pose risks of secondary pollution.$^{[14,7,8]}$ However a novel approach, phytoremediation, has emerged and aroused high interest$^{[9–13]}$. In phytoremediation a specific plant (hyperaccumulator) is used to absorb the heavy metals from the soil, next the plant is harvested, removed from the contaminated site and appropriately processed by burning and burying the residue deeply. In some cases the heavy metals are extracted from the ash. In recent years the prospects...
for using phytoremediation have improved substantially because of discoveries that
certain plant species are hyperaccumulators of heavy metals.\cite{7,14-16} However no
hyperaccumulator has been introduced into practice in China. Thus some
alternative approaches must be explored, such as growing inedible plants or tolerant
crops in accordance with appropriate ecological engineering strategies.\cite{4,8}

In order to select an effective and practical approach for soil remediation,
we must first understand the status and characteristics of soil and plant con-
tamination, the distribution of metals within plants, various contributing factors to
contamination and the sources of the heavy metals. Therefore, we investigated soil
and plant contamination with heavy metals at several apparently polluted sites
in China, the source of the metals, the effect of pH on bioavailability, metal uptake,
distribution in plant parts and potential applications in soil pollution control. Finally
we identified some specific plants that have the ability to concentrate significant
quantities of heavy metals. In addition we suggest that certain plants may be
genetically improved to serve as more effective hyperaccumulators, and that the
genes for the capacity to exclude the uptake of heavy metals may be transferred
into crop varieties for growing on contaminated soils to produce safe food.

**MATERIALS AND METHODS**

**Locations Investigated and Sampled**

The investigation sites were located at the Beijing Capital Steel Plant, the waste-
water irrigation area near Beijing, the Tangshan Steel and Iron Manufacturing
facility at Tangshan, Hebei Province, the mining and tailing disposal areas of
Pb/Zn ore in Liaoning Province and the Shenzhen high technology development
zone in Guangdong Province (Table 1).

<table>
<thead>
<tr>
<th>Location</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing Capital Steel Plant, Beijing.</td>
<td>Heavy metal industrial area with in which smelting and</td>
</tr>
<tr>
<td></td>
<td>metal processing had been conducted more than 40 years.</td>
</tr>
<tr>
<td>Tangshan Iron &amp; Steel making facility, Tangshan, Hebei Province.</td>
<td>Dominant industrial facility in which smelting iron and</td>
</tr>
<tr>
<td></td>
<td>steel processing had been conducted more than 50 years.</td>
</tr>
<tr>
<td>Pb and Zn ore mining site, Liaoning Province.</td>
<td>Mining began during the 1950s; vast amounts of tailings have</td>
</tr>
<tr>
<td></td>
<td>been disposed.</td>
</tr>
<tr>
<td>Shenzhen High Technology Zone, Shenzhen, Guangdong Province.</td>
<td>A new city for high technology industries being</td>
</tr>
<tr>
<td></td>
<td>developed since the 1980s adjacent to Hong Kong</td>
</tr>
<tr>
<td>Qinghe untreated wastewater irrigation area, Beijing.</td>
<td>A farming area irrigated for 30 years with wastewater</td>
</tr>
<tr>
<td></td>
<td>discharged mainly from urban dwellings.</td>
</tr>
</tbody>
</table>

Table 1. Description of sites investigated for contamination with heavy metals.
At each site three to five samples of soil at 0–15 cm in depth were taken. The samples were associated with plants, surface water, tailings or sewage sludge. For atmospheric deposition at distances between 100 to 5000 meters from a Pb/Zn smelter, the soil samples were taken at random but with care to exclude other possible sources of contaminants, such as wastewater, sludge, etc.

In addition samples were taken of trees, shrubs, paddy rice, wheat, corn, vegetables and weeds. Only the leaves of trees were sampled. However the edible parts of vegetables were sampled. In the case of the other food crops, the whole plants, including roots, shoots, leaves, and fruits were collected at maturity and then separated into different parts. Only the shoots and roots of *Rumex acetosa* L. were available.

### Pretreatment

The soil samples were air-dried under ambient conditions. Tiny roots and other residues were removed before the soil was ground and sieved. The plant samples were washed lightly with tap water, rinsed with deionized water to remove surface dust, dried with Whatman filter papers, dehydrated in a ventilation oven at 105°C for 2 h and then stored at 75°C for 48 h. The dried plant samples were cut into small pieces with stainless steel scissors before being ground in an agate mill. Care was taken to prevent contamination at all steps in the process.

### Digestion and Analysis

Both soil and plant samples were digested with concentrated HNO₃ associated with HF and HClO₄. All the containers were soaked at least 24 h with 2% of nitric acid before use. Chemical analyses were performed using an atomic absorption spectrometer with graphite furnace atomization (GFAAS) and deuterium background correlation for Cd, and with inductively coupled plasma atomic emission spectroscopy (ICP-AES), and with an atomic absorption spectrometer with flame furnace atomization (FFAAS) for the other elements. The recovery ratios between 92 to 105% were controlled throughout the procedures. The extractions of heavy metals in soil samples were carried out with 1 M NH₄OAc and determined as above. Soil pH was measured in a slurry of soil-water (ratio of 1:5) with an H⁺ analyzer (pHS-3).

### Statistics and Analysis of Data

Data were subjected to the ANOVA, and subsequently to Fisher’s protected least significant difference (LSD) for comparisons of means. To assess the contamination status, the Government Standards or guidelines from the China State Environmental Protection Administration (CSEPA) for heavy metals in soils, vegetables or food crops were consulted as appropriate.
RESULTS

Soil Contamination Status

Concentrations of Metals in Soils

Concentrations of 7 metals were compared with the background values. Most samples had higher concentrations of heavy metals than the background. However, lower than background concentrations of Mn, Cr, Ni, and Cu were found in some samples and Cd was not detected in samples from one site. In most instances, Zn and Cd concentrations exceeded the government standards (Zn \(\leq 250 \text{ mg kg}^{-1}\), Pb \(\leq 300 \text{ mg kg}^{-1}\), Cd \(\leq 0.6 \text{ mg kg}^{-1}\) at pH 6.5–7.5) (GB15618-1995). The Zn concentrations at the various sites ranged from 198 to 980 mg kg\(^{-1}\) and up to 6.32 mg kg\(^{-1}\) of Cd occurred at the tailings disposal site, Liaoning Province (Table 2).

When metal concentrations were examined with respect to location or land utilization, the mining area had high concentrations of Pb, Cd, Mn, and Zn. Soil samples from a green park near a smelter at Beijing contained high concentrations of Cd, Mn, Cr, Ni, and Cu. In the soils of three areas irrigated with untreated wastewater near Beijing, Zn was highly concentrated, while Pb and possibly Cu were concentrated somewhat (Table 2).

Extractable Concentrations of Metals

The extractable concentrations of metals (Table 3) are considered to represent their bioavailability. Extractable concentrations of Cr, Cd, and Pb were well correlated with their total concentrations in the soil samples, but not in the cases of other heavy metals (Table 4). The extractable concentrations of Pb, Zn, Cd, and Cu in the samples from Pb/Zn tailings disposal area in Liaoning Province were significantly higher than from the other sites (Table 3). Furthermore, high concentrations of extractable Mn and Pb were found in the samples from Shenzhen, Guangdong Province although the concentrations of these metals in the soil at this site were not nearly as high as in soils at other sites (Table 3). This result is possibly related to the low pH (5.3) of this highly leached soil.

From Table 3, it is easy to notice that prevalence of one metal was coupled to that of one or more others. Thus the prevalence of Mn was coupled to that of Cd, Pb with Ni, Cr with Ni and Zn, Cu with Zn and Ni, Cd with Pb, etc. This implies that Pb occurs together with Cd, Mn, Cu, and Zn, but Cr occurs together with Ni and Mn.

Soil Heavy Metal Uptake by Plants

Concentrations of Metals in Plants

The concentrations of some metals, especially Zn and Cd in trees and some other plants were relatively high. Also the concentrations of Zn, Cd, and Cr in paddy rice
and vegetables were obviously high (Table 5). Metal concentrations in the leaves of various plants differed significantly. Thus privet had almost 10 mg kg\(^{-1}\) of Cd, but Boston ivy had less than 1 mg kg\(^{-1}\). Amorpha had up to 780 mg kg\(^{-1}\) of Zn, but in chinar from the same location Zn could not be detected (Table 5).

In Polygonum hydropiper taken from a sewage pond, Zn was concentrated at 1061 mg kg\(^{-1}\) and almost as high concentrations of Zn were found in Rumex acetosa

Table 2. Total concentrations of heavy metals in soils (mg kg\(^{-1}\)) of sites suspected of being polluted.

<table>
<thead>
<tr>
<th>Location</th>
<th>Mn</th>
<th>Cr</th>
<th>Cu</th>
<th>Zn</th>
<th>Cd</th>
<th>Pb</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green park adjacent to smelter of Capital Steel Plant, Beijing.</td>
<td>1004.24</td>
<td>101.69</td>
<td>38.14</td>
<td>294.49</td>
<td>4.24</td>
<td>127.12</td>
<td>52.97</td>
</tr>
<tr>
<td>Tailings disposal area for Pb/Zn ore mining, Liaoning Province.</td>
<td>1001.21</td>
<td>56.91</td>
<td>43.02</td>
<td>399.58</td>
<td>6.32</td>
<td>214.78</td>
<td>22.76</td>
</tr>
<tr>
<td>Dachengshan botanical garden, near Tangshan iron/steel factory, Tangshan, Hebei Province.</td>
<td>926.17</td>
<td>81.79</td>
<td>46.42</td>
<td>439.88</td>
<td>2.21</td>
<td>161.36</td>
<td>40.23</td>
</tr>
<tr>
<td>Farmland in Pb/Zn ore mining area, Liaoning Province.</td>
<td>880.71</td>
<td>86.21</td>
<td>37.28</td>
<td>983.22</td>
<td>1.02</td>
<td>102.52</td>
<td>36.81</td>
</tr>
<tr>
<td>Groves near smelter, Capital Steel Plant, Beijing.</td>
<td>560.38</td>
<td>17.38</td>
<td>34.75</td>
<td>197.65</td>
<td>2.17</td>
<td>195.48</td>
<td>9.56</td>
</tr>
<tr>
<td>Farmland close to Capital Steel Plant, Mentougou District, Beijing.</td>
<td>531.25</td>
<td>48.08</td>
<td>72.12</td>
<td>466.35</td>
<td>2.40</td>
<td>69.71</td>
<td>38.94</td>
</tr>
<tr>
<td>Vegetable field irrigated with wastewater from Qinghe River, Beijing.</td>
<td>380.82</td>
<td>57.22</td>
<td>33.54</td>
<td>576.16</td>
<td>1.97</td>
<td>71.03</td>
<td>26.05</td>
</tr>
<tr>
<td>Green land of Lianhuashan, Hill, Shenzhen, Guangdong Province.</td>
<td>366.86</td>
<td>51.26</td>
<td>22.38</td>
<td>213.26</td>
<td>1.12</td>
<td>98.62</td>
<td>18.98</td>
</tr>
<tr>
<td>Farmland in the vicinity of Tangshan Iron &amp; Steel Factory.</td>
<td>359.86</td>
<td>69.86</td>
<td>16.93</td>
<td>370.45</td>
<td>n.d.</td>
<td>29.64</td>
<td>35.35</td>
</tr>
<tr>
<td>Paddy rice field with irrigated with wastewater from Qinghe River, Beijing.</td>
<td>334.53</td>
<td>70.14</td>
<td>34.17</td>
<td>926.26</td>
<td>1.80</td>
<td>86.33</td>
<td>30.22</td>
</tr>
<tr>
<td>Nursery bed irrigated with wastewater from Qinghe River, Beijing.</td>
<td>327.51</td>
<td>61.14</td>
<td>32.75</td>
<td>401.75</td>
<td>2.18</td>
<td>159.39</td>
<td>29.26</td>
</tr>
<tr>
<td>Industrial area, Shenzhen, Guangdong Province.</td>
<td>258.23</td>
<td>45.52</td>
<td>36.82</td>
<td>326.25</td>
<td>2.38</td>
<td>75.25</td>
<td>23.12</td>
</tr>
<tr>
<td>L.S.D. ((P &lt; 0.05))</td>
<td>360.29</td>
<td>34.59</td>
<td>18.54</td>
<td>275.00</td>
<td>1.25</td>
<td>65.91</td>
<td>16.90</td>
</tr>
<tr>
<td>Soil background value(^{b})</td>
<td>583.00</td>
<td>61.00</td>
<td>22.60</td>
<td>74.20</td>
<td>0.097</td>
<td>26.00</td>
<td>26.90</td>
</tr>
</tbody>
</table>

\(^{a}\)n.d. means that the content was not detected at the level of \(\leq 0.001\mu g \text{m}^{-1}\); \(^{b}\)China National Environmental Protection Administration (1990).
growing near the smelter in Beijing (Table 5). Also the paddy rice and vegetables irrigated with untreated wastewater from urban dwellings in Beijing contained high concentrations of heavy metals, especially by Zn, Cr, and Cd (Table 5).

The Distribution of Heavy Metals in Plants

The distribution of metals in different plant parts varied depending on the metal and the crop. For example, high concentrations of Cd, Cr, and Zn (22–24%) were
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</thead>
<tbody>
<tr>
<td>Extrac. Mn</td>
<td>0.155</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Total Cr</td>
<td>0.576a</td>
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<td>—</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Extrac. Cr</td>
<td>0.494</td>
<td>-0.100</td>
<td>0.546a</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Total Cu</td>
<td>0.473</td>
<td>0.334</td>
<td>0.323</td>
<td>0.065</td>
<td></td>
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<td></td>
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<tr>
<td>Extrac. Cu</td>
<td>0.313</td>
<td>0.373</td>
<td>-0.181</td>
<td>-0.171</td>
<td>0.322</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Total Zn</td>
<td>0.338</td>
<td>0.245</td>
<td>0.540a</td>
<td>-0.059</td>
<td>0.758b</td>
<td>-0.024</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Extrac. Zn</td>
<td>0.466</td>
<td>0.452</td>
<td>-0.030</td>
<td>-0.054</td>
<td>0.158</td>
<td>0.752b</td>
<td>0.033</td>
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</tr>
<tr>
<td>Total Cd</td>
<td>0.569a</td>
<td>0.351</td>
<td>0.138</td>
<td>0.360</td>
<td>0.497</td>
<td>0.578a</td>
<td>0.148</td>
<td>0.736b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extrac. Cd</td>
<td>0.405</td>
<td>0.401</td>
<td>-0.093</td>
<td>-0.070</td>
<td>0.054</td>
<td>0.747b</td>
<td>-0.073</td>
<td>0.988b</td>
<td>0.701b</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Total Pb</td>
<td>0.548a</td>
<td>0.135</td>
<td>-0.116</td>
<td>0.076</td>
<td>0.156</td>
<td>0.2575</td>
<td>-0.068</td>
<td>0.551a</td>
<td>0.620a</td>
<td>0.578a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extrac. Pb</td>
<td>0.393</td>
<td>0.389</td>
<td>-0.105</td>
<td>-0.078</td>
<td>-0.012</td>
<td>0.738b</td>
<td>-0.118</td>
<td>0.983b</td>
<td>0.661b</td>
<td>0.991b</td>
<td>0.541a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Ni</td>
<td>0.544a</td>
<td>-0.091</td>
<td>0.889b</td>
<td>0.556</td>
<td>0.540a</td>
<td>-0.006</td>
<td>0.519</td>
<td>-0.128</td>
<td>0.193</td>
<td>-0.199</td>
<td>-0.201</td>
<td>-0.226</td>
<td></td>
</tr>
<tr>
<td>Extrac. Ni</td>
<td>0.407</td>
<td>0.350</td>
<td>0.399</td>
<td>0.170</td>
<td>0.883b</td>
<td>0.038</td>
<td>0.783b</td>
<td>0.117</td>
<td>0.421</td>
<td>-0.003</td>
<td>0.097</td>
<td>-0.064</td>
<td>0.503</td>
</tr>
</tbody>
</table>

Note: a significance at $P < 0.05$; b significance at $P < 0.01$ ($r_{0.05} = 0.535$, $r_{0.01} = 0.661$).
accumulated in unpolished rice seed. By contrast Mn, Pb, and Cu (39–82%) were heavily concentrated in the roots, and only 3–9% of these three metals had been translocated into the seeds (Fig. 1). With respect to Cd, Cu, and Pb in wheat and corn (Fig. 2), wheat accumulated more of these metals in the seeds than corn, but corn accumulated more of the metals in the shoots than wheat. Corn accumulated most of the Cu in the roots (Fig. 2). *Rumex acetosa* accumulated roughly equal amounts of the various metals in the roots and shoots, with the exception of Ni, which was accumulated predominantly in the roots (Fig. 3). Remarkably *Rumex acetosa* strongly accumulated Zn in its shoots and roots with concentrations exceeding 900 mg kg\(^{-1}\) (Fig. 3).

A further investigation showed that the same plant species growing at different locations accumulated substantially different amounts of a given metal. For

Table 5. Heavy metal concentrations in different plants at polluted sites (mg kg\(^{-1}\)).

<table>
<thead>
<tr>
<th>Plants</th>
<th>Mn</th>
<th>Cr</th>
<th>Cu</th>
<th>Zn</th>
<th>Cd</th>
<th>Pb</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trees</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweeping willow (<em>Salix babylonica</em> L.)</td>
<td>104.70</td>
<td>113.66</td>
<td>211.54</td>
<td>666.67</td>
<td>2.32</td>
<td>72.65</td>
<td>–</td>
</tr>
<tr>
<td>Privet (<em>Ligustrum lucidum</em>)</td>
<td>84.94</td>
<td>131.88</td>
<td>114.78</td>
<td>780.53</td>
<td>1.34</td>
<td>91.83</td>
<td>–</td>
</tr>
<tr>
<td>Amorpha (<em>Amorpha fruticosa</em> L.)</td>
<td>70.28</td>
<td>25.63</td>
<td>28.11</td>
<td>506.02</td>
<td>9.73</td>
<td>160.64</td>
<td>–</td>
</tr>
<tr>
<td>Boston ivy (<em>Parthenocissus tricuspidata</em>)</td>
<td>60.67</td>
<td>53.41</td>
<td>744.77</td>
<td>696.65</td>
<td>0.87</td>
<td>75.31</td>
<td>–</td>
</tr>
<tr>
<td>Tree of heaven (<em>Ailanthus altissima</em> Mill)</td>
<td>57.07</td>
<td>144.77</td>
<td>39.51</td>
<td>730.90</td>
<td>2.75</td>
<td>223.88</td>
<td>–</td>
</tr>
<tr>
<td>Common juniper (<em>Juniperus formosana</em>)</td>
<td>36.59</td>
<td>108.11</td>
<td>14.23</td>
<td>632.11</td>
<td>1.36</td>
<td>75.20</td>
<td>–</td>
</tr>
<tr>
<td>Cottonrose hibiscus (<em>Hibiscus mutabilis</em>)</td>
<td>36.20</td>
<td>36.49</td>
<td>11.43</td>
<td>485.90</td>
<td>1.43</td>
<td>49.54</td>
<td>–</td>
</tr>
<tr>
<td>Chinese pine (<em>Pinus tabulaeformis</em> carr.)</td>
<td>n.d.</td>
<td>9.16</td>
<td>8.61</td>
<td>114.03</td>
<td>1.44</td>
<td>21.51</td>
<td>–</td>
</tr>
<tr>
<td>Chinar (<em>Platanus acerifolia</em> Willd)</td>
<td>n.d.</td>
<td>4.06</td>
<td>n.d.</td>
<td>n.d.</td>
<td>2.07</td>
<td>13.37</td>
<td>–</td>
</tr>
<tr>
<td><strong>L.S.D. (P &lt; 0.05)</strong></td>
<td>24.64</td>
<td>36.94</td>
<td>132.20</td>
<td>256.46</td>
<td>1.29</td>
<td>49.67</td>
<td>–</td>
</tr>
<tr>
<td><strong>Field crops (shoots)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paddy rice (<em>Oryza sativa</em> L.)</td>
<td>206.08</td>
<td>365.40</td>
<td>7.36</td>
<td>738.47</td>
<td>4.30</td>
<td>73.60</td>
<td>–</td>
</tr>
<tr>
<td>Winter wheat (<em>Triticum aestivum</em>)</td>
<td>55.34</td>
<td>42.25</td>
<td>3.54</td>
<td>169.20</td>
<td>0.12</td>
<td>33.25</td>
<td>–</td>
</tr>
<tr>
<td>Corn (<em>Zea mays</em> L.)</td>
<td>32.31</td>
<td>25.52</td>
<td>2.53</td>
<td>825.52</td>
<td>0.54</td>
<td>45.32</td>
<td>–</td>
</tr>
<tr>
<td><strong>L.S.D. (P &lt; 0.05)</strong></td>
<td>85.25</td>
<td>105.56</td>
<td>3.68</td>
<td>354.25</td>
<td>3.42</td>
<td>35.32</td>
<td>–</td>
</tr>
<tr>
<td><strong>Vegetables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cayenne (<em>Capsium annum</em> var.)</td>
<td>32.20</td>
<td>548.06</td>
<td>18.40</td>
<td>701.47</td>
<td>4.80</td>
<td>78.20</td>
<td>–</td>
</tr>
<tr>
<td>Cucumber (<em>Cucumis sativus</em>)</td>
<td>31.91</td>
<td>407.42</td>
<td>17.02</td>
<td>676.17</td>
<td>3.84</td>
<td>69.00</td>
<td>–</td>
</tr>
<tr>
<td>Carob (<em>Vigna sesquipedalis</em> L.)</td>
<td>29.90</td>
<td>401.26</td>
<td>23.00</td>
<td>723.44</td>
<td>3.63</td>
<td>75.55</td>
<td>–</td>
</tr>
<tr>
<td>Leek (<em>Allium tuberosum</em>)</td>
<td>29.76</td>
<td>365.33</td>
<td>22.89</td>
<td>598.11</td>
<td>3.59</td>
<td>51.64</td>
<td>–</td>
</tr>
<tr>
<td>Eggplant (<em>Solanum melongena</em> L.)</td>
<td>25.82</td>
<td>439.45</td>
<td>17.21</td>
<td>38.26</td>
<td>3.86</td>
<td>75.25</td>
<td>–</td>
</tr>
<tr>
<td><strong>L.S.D. (P &lt; 0.05)</strong></td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>38.26</td>
<td>–</td>
</tr>
<tr>
<td><strong>Weeds or grasses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Rumex acetosa</em> L. at sewage pond</td>
<td>342.53</td>
<td>19.03</td>
<td>865.84</td>
<td>601.81</td>
<td>2.38</td>
<td>85.63</td>
<td>5.23</td>
</tr>
<tr>
<td><em>Rumex acetosa</em> L. at a smelter</td>
<td>24.02</td>
<td>24.02</td>
<td>12.01</td>
<td>929.39</td>
<td>2.40</td>
<td>69.64</td>
<td>2.16</td>
</tr>
<tr>
<td><em>Polygonum hydropiper</em> at sewage pond</td>
<td>92.94</td>
<td>23.23</td>
<td>13.94</td>
<td>1061.80</td>
<td>2.32</td>
<td>65.06</td>
<td>4.41</td>
</tr>
<tr>
<td><em>Polygonum hydropiper</em> from field</td>
<td>46.99</td>
<td>16.45</td>
<td>14.10</td>
<td>742.48</td>
<td>2.35</td>
<td>77.54</td>
<td>4.70</td>
</tr>
<tr>
<td><em>Stramonium</em> (<em>Datura stramonium</em> L.)</td>
<td>83.48</td>
<td>17.12</td>
<td>83.48</td>
<td>851.88</td>
<td>2.14</td>
<td>42.81</td>
<td>3.42</td>
</tr>
<tr>
<td><em>Kochia</em> (<em>Kochia scoparia</em> L.)</td>
<td>50.55</td>
<td>16.08</td>
<td>13.79</td>
<td>838.69</td>
<td>2.30</td>
<td>71.23</td>
<td>5.51</td>
</tr>
<tr>
<td><strong>L.S.D. (P &lt; 0.05)</strong></td>
<td>62.54</td>
<td>147.90</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.</td>
<td>25.23</td>
<td>1.56</td>
</tr>
</tbody>
</table>
Figure 1. Percent distribution of various metals in different parts of paddy rice irrigated with polluted water.

Figure 2. Relative percentages of Cd (left), Cu (middle) and Pb (right) taken up by the different organs of corn and wheat.

Figure 3. The distribution of various metals in the shoots and roots of *Rumex acetosa*. 
example, *Rumex acetosa* growing near a smelter had accumulated 865 and 342 mg kg\(^{-1}\) of Cu and Mn, respectively, and these amounts are 71 and 13 times greater than those accumulated by *Rumex acetosa* plants growing in the sewage pond. Likewise *Polygonum hydropiper* growing at the sewage pond accumulated 1061 mg kg\(^{-1}\) of Zn, but only 742 mg kg\(^{-1}\) when growing in a field (Table 4). These differences may indicate that either different races of these species exist, or that these species have adapted in different ways to the adverse soil environments.

### The Major Sources of Heavy Metals

#### Industrial or Domestic Wastewater for Irrigation

Among the wastewater from different sources, only Cd concentrations exceeded the Government Standard for irrigation water used on farmland (Table 6). Nevertheless repeated applications over many years can be expected to result in excessive accumulation of heavy metals in soils.

#### Disposal of Slurry from Ore Mining and Sewage Sludge Application

The total concentrations of Mn, Pb and Zn in the tailings of a Pb/Zn ore were roughly 1000 mg kg\(^{-1}\), and the extractable quantities of Pb and Zn in these tailings were 70 and 23 mg kg\(^{-1}\) DW, respectively (Fig. 4a). The extractable concentrations of Mn and Zn in sewage sludge from the heavily polluted Qinghe River bed were 7 and 4 mg kg\(^{-1}\), respectively (Fig. 4b). Clearly the improper disposal of tailings or sewage sludge can be expected to contaminate soils excessively.

#### Atmospheric Deposition

The vicinities of heavy industries, smelters or mining sites are vulnerable to the atmospheric deposition of heavy metals, so that such deposition may contribute significantly to the concentrations of metals in soils. Indeed at the distances

### Table 6. Heavy metal concentration of samples from polluted waters (mg L\(^{-1}\)).

<table>
<thead>
<tr>
<th>Sources</th>
<th>Mn</th>
<th>Cr</th>
<th>Cu</th>
<th>Zn</th>
<th>Cd</th>
<th>Pb</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater from mining</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.22</td>
<td>0.014</td>
<td>0.19</td>
<td>0.027</td>
</tr>
<tr>
<td>Wastewater from a smelter</td>
<td>0.01</td>
<td>0.03</td>
<td>0.07</td>
<td>0.04</td>
<td>0.010</td>
<td>0.16</td>
<td>0.026</td>
</tr>
<tr>
<td>Domestic wastewater in Qinghe</td>
<td>0.04</td>
<td>0.03</td>
<td>0.01</td>
<td>0.05</td>
<td>0.0086</td>
<td>0.16</td>
<td>0.024</td>
</tr>
<tr>
<td>River, Beijing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.S.D. (P &lt; 0.05)</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.01</td>
<td>0.05</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Guideline in water quality</td>
<td>–</td>
<td>≤ 0.1</td>
<td>≤ 1.0</td>
<td>≤ 2.0</td>
<td>≤ 0.002</td>
<td>≤ 0.5</td>
<td>–</td>
</tr>
<tr>
<td>for irrigation (GB5084-85)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Chen, 1996)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
between 100 and 5000 meters from a smelter, Pb, Zn, and Cd concentrations displayed an exponential correlation with distance \( (x) \): 

\[
Pb = 498.16e^{-0.0004x},
\]

\[
Zn = 225.95e^{-0.0003x},
\]

\[
Cd = 9.6621e^{-0.0003x}
\]

with \( R^2 \) values of 0.9748, 0.9564 and 0.9183, respectively (Fig. 5).

**DISCUSSION**

This investigation has revealed substantial Zn and Cd contamination of the soil at some sites. These findings substantiate the findings of our previous report.
and of other investigators\[3,18\] that soil Cd and Zn contamination pose significant risks to health of people living in the vicinities of these sites. The effects of heavy metals on ecosystems, the environment or on human health usually depends on the bioavailability of the metal rather than on the total amount in soil. The extractable amounts of soil metals seem to be of more practical significance for the assessment of soil contamination. However, based on our investigations, there appear no correlation between the concentrations of heavy metals in plants and extractable levels in calcareous soil (data not shown). However in the present study some metals, especially Cd, Pb, and Cr, displayed close relationships between the total amounts in the soil and the extractable amounts (Table 4). The reason for this relationship is to be found in the properties of the soil, and this is evident from the fact that the bioavailabilities of these metals is higher in acidic than in alkaline or neutral soils. Fortunately, the investigated sites are located in both acidic and calcareous soil zones with large differences in pH values. Figure 6 shows that concentrations of soil extractable metals were inversely correlated with soil pH.

The accumulation of heavy metals differed greatly between the various species of plants. For instance, Zn content in leaves of the privet plant reached 780 mg kg\(^{-1}\), but Zn could not be detected in the leaves of chinar. Privet possesses a specific mechanism for strongly concentrating heavy metals, whereas chinar appears to have a mechanism that excludes the uptake of heavy metals. The elucidation and characterization of these contrasting mechanisms is strongly warranted. The mechanism in privet is significant for phytoremediation, while the mechanism in chinar has potential for application in producing “hygienic food” from plants growing in the various polluted or “unhygienic soils.”\[19\] Thus it would be of considerable benefit to characterize the mode of inheritance of these traits and to transfer the genes that determine them into edible crops.

In most plants, heavy metals are accumulated in the roots rather than in the shoots or fruits. Thus we found that Cu is accumulated largely in the roots and shoots of paddy rice, corn and Rumex acetosa. Obviously a limitation in the use of hyperaccumulators, which concentrate metals in their roots, for phytoremediation is that it would be necessary to harvest their roots in order to efficiently remove the heavy metal pollutant from the soil. Certainly this is not an insurmountable difficulty. Nevertheless the hyperaccumulators are defined as plants that concentrate...
metals in shoots or other above ground organs in high concentrations. These recommended concentrations should for various metals be as follows: \( \text{Cd} \geq 100 \text{ mg kg}^{-1} \); \( \text{Co}, \text{ Cu}, \text{ Ni}, \text{ and Pb} \geq 1,000 \text{ mg kg}^{-1} \) and, \( \text{Mn} \text{ and Zn} \geq 10,000 \text{ mg kg}^{-1} \)[7,20,21]. In accordance with this definition, none of the plant species studied in this investigation can be classified as an hyperaccumulator. Nevertheless \( \text{Polygonum hydropiper} \) accumulated up to 1061 mg kg\(^{-1}\) of Zn, while \( \text{Rumex acetosella} \) growing near a smelter accumulated more than 900 mg kg\(^{-1}\) Zn in its shoots and roots. However \( \text{Rumex acetosella} \) growing in a sewage pond accumulated somewhat lesser amounts (Table 4). This reduced accumulation in the sewage pond may be an effect of that particular environment on the physiology of \( \text{Rumex acetosella} \), since this species has also been found to accumulate various amounts of Cu in the range of 340–1102 mg kg\(^{-1}\) in another area[22] and in our study we found 865 mg kg\(^{-1}\) of Cu in its shoots (Table 4).

The distribution of heavy metals in various parts of crops implies that it would be a high risk to human health if paddy rice were grown in soils heavily contaminated with Cd, Cr, and Zn, since a large proportion of those metals accumulated in the edible parts (Fig. 1) that enter directly into the food supply. Perhaps this is the major cause of the rampant itai-itai disease in Japan.[6] However, growing paddy rice in soil contaminated with Cu, Mn or Pb would be less risky because these metals are accumulated mostly in the roots with only very little in the grain (Fig. 1). With respect to wheat with corn, two major crops in northern China, growing corn rather than wheat in Cu, Cd or Pb contaminated soil would entail a smaller risk of the occurrence of excessive levels of these elements in the food supply (Fig. 2). These results suggest that by developing an accurate and reliable understanding of the distribution of metals in the organs of various crop species, it will be possible to choose certain crops[8] or employ certain crop rotations to prevent edible plant parts from becoming contaminated with heavy metals.

**CONCLUSION**

Our results show that special attention should be paid to Cd and Zn contamination in soils in the vicinities of heavy industries, ore mines and untreated wastewater irrigation areas. Concentrations of heavy metals in the soil, such as Cd, Cr and Pb, were closely correlated with the extractable amounts. Therefore, either the total concentration in the soil or the extractable contents can be used to assess soil heavy metal contamination in accordance with corresponding standards. However, for assessing the bioavailability of metals the pH of the soil should be taken account. Our investigation showed that \( \text{Polygonum hydropiper} \) is able to accumulate as high as 1061 mg kg\(^{-1}\) of Zn. Therefore this species probably is of value for use in the remediation of contaminated soils, although additional relevant research and development would be required to develop a practical technology. Metal contaminants of soils were found to originate mainly from wastewater, atmospheric deposition, disposal of slurries or tailings from mining operations and from the application of sewage sludge to farmland. Lightly contaminated soils can be utilized for production of food crops, provided that crops are grown that accumulate only small amounts of toxic metals in edible parts of the crop.
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