Assessment and mapping of environmental quality in agricultural soils of Zhejiang Province, China

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Abstract

Heavy metal concentrations in agricultural soils of Zhejiang Province were monitored to indicate the status of heavy metal contamination and assess environmental quality of agricultural soils. A total of 908 soil samples were collected from 38 counties in Zhejiang Province and eight heavy metal (Cd, Cr, Pb, Hg, Cu, Zn, Ni and As) concentrations had been evaluated in agricultural soil. It was found 775 samples were unpolluted and 133 samples were slightly polluted and more respectively, that is approximately 14.65% agricultural soil samples had the heavy metal concentration above the threshold level in this province by means of Nemerow’s synthetical pollution index method according to the second grade of Standards for Soil Environmental Quality of China (GB15618-1995). Contamination of Cd was the highest, followed by Ni, As and Zn were lower correspondingly. Moreover, Inverse Distance Weighted (IDW) interpolation method was used to make an assessment map of soil environmental quality based on the Nemerow’s pollution index and the soil environmental quality was categorized into five grades. Moreover, ten indices were calculated as input parameters for principal component analysis (PCA) and the principal components (PCs) were created to compare environmental quality of different soils and regions. The results revealed that environmental quality of tea soils was better than that of paddy soils, vegetable soils and fruit soils. This study indicated that GIS combined with multivariate statistical approaches proved to be effective and powerful tool in the mapping of soil contamination distribution and the assessment of soil environmental quality on provincial scale, which is beneficial to environmental protection and management decision-making by local government.

Key words: agricultural soil; heavy metals; soil environmental quality; Nemerow’s synthetical pollution index; multivariate analysis

Introduction

As being a kind of non-renewable natural resources and the foundation of human being’s subsistence and development, soil serves many vital functions in our society, particularly for food production. It is thus extremely important to protect this resource and ensure its sustainability. Deterioration of environment conditions and increasing reliance on agrochemicals have led to a growing public concern over the potential accumulation of heavy metals and other contaminants in agricultural soils (Wong et al., 2003; Nicholson et al., 2003). When heavy metals present high concentration in agricultural soils, they are known not only to affect the crops output and quality, but also result in the further deterioration growth, morphology and metabolism of micro-organisms in soils (Dietrich et al., 1990; Muller, 1994; Giller et al., 1998), and adversely affect agricultural production and water quality inevitably, which could enhance the risk of metal contamination of food chains (Frangi and Richard, 1997; Younas et al., 1998; Mclaughlin et al., 1999).

Along with the developed coastal region of eastern China, such as Zhejiang Province, a consequence of industrialization and urbanization have caused significant impacts on the local environment because of lacking pollution controls. Zhejiang Province is located in the southern wing of the Yangtze River Delta on the southeastern coast of China and borders Shanghai City to the north. Zhejiang is now a province of strong economy with industry as the guiding sector and a large number of pollutants are spreaded in the atmosphere: gaseous harmful materials, solid materials and aerosols which contain organic as well as inorganic harmful materials, toxic elements and heavy metals contamination of agricultural soils has become increasingly serious (Li et al., 1997; Chen et al., 1999).

Since a survey of soil heavy metal contents might supply some fundamental information for the environmental planning, extensive investigations of agricultural soils have been carried out in some countries and regions in recent years (Elsokkary et al., 1995; Burn et al., 1998; Abollino et al., 2002; Adamo et al., 2003) and some works (Li et al., 2001; Wang, 2002; Wang et al., 2003; Zhang and Ke, 2004) also have been carried out to evaluate the heavy
metal contamination of some cities or drainage areas in China, however, there is a few detailed and systematically study have been undertaken to investigate the heavy metal contents in agricultural soil on a provincial scale in China. The present study was carried out as a part of the agro-geology environment investigation in Zhejiang Province. The objectives of this study were to (1) indicate the status of heavy metal contamination; (2) assess and map the environmental quality in agricultural soils of Zhejiang Province.

1 Materials and methods

1.1 Soil sampling and analysis

A total of 908 soil samples were collected from 38 counties in Zhejiang Province (Fig.1). Among these samples, 303 were from fruit land, 261 from paddy field, 136 from tea garden and 208 from vegetable land, respectively. A Trimble Pro-XR Global Positioning System (GPS, Trimble, USA), operated in differential mode with real-time GPS corrections, was used to locate each sampling point to within ± 5 m. Composite soil samples were taken from each of these sampling points. Using quincunx-sampling method, 5 soil cores were collected to a depth of 20 cm in a 25-m rectangle of each grid node, and then bulked to give a composite sample.

Soil samples were air-dried at 30°C and sieved through a 2-mm polyethylene sieve. After digestion with a mixed acid of aqua fortis, nitric acid (HNO₃), fluorin acid (HF) and chlorine acid (HClO₄), heavy metal contents were determined according to the national standard methodologies (NSPRC, 1995). Concentrations of Cd, Pb, Cu, Cr, Ni and Zn were determined using an inductively coupled plasma-mass spectrometry (ICP-MS; POEMS 3, Thermo Electron, USA). Applying atomic spectro-fluorophotometer (AFS, XGY-1011A, IGGE, China) to detect the concentrations of As, Hg. Standard reference material, GSS-1 soil was obtained from the Institute of Geophysical and Geochemical Prospecting, Department of Geology and Minerals of China, was used as quality assurance measure for the analyses of total heavy metals and incorporated during the analysis.

1.2 Data analysis

Nemerow’s synthetical pollution index was applied to assess soil environmental quality in previous study (Liu et al., 2004). In the present study, this method was utilized for the degree of soil environmental pollution and integrative assessment of soil environmental quality, the Standards Soil Environmental Quality (GB15618-1995) was used as soil quality assessment criteria. Its equation is as follows:

\[ P_n = \sqrt{(\text{Max}_i^2 + \bar{P}_i^2)}/2 \]  

Where,

\[ P_i = C_i/S_i \]

\[ P_n \] is the Nemerow’s synthetical pollution index, \( P_i \) is the pollution index of the \( i \)th heavy metal, \( C_i \) is the measured concentration of the \( i \)th heavy metal, \( S_i \) is the required standard of the \( i \)th heavy metal, \( \bar{P}_i \) and max\( P_i \) is the average and the maximum value of the pollution indices of all heavy metals respectively.

The Nemerow’s synthetical pollution index \( P_n \) for all the soil sampling points was calculated to show the relative magnitudes of soil pollution. Higher value for \( P_n \) indicates more serious pollution. According to GB15618-1995, soil environmental quality was classified into 5 grades from Nemerow’s synthetical pollution index. The classification criterions are presented in Table 1.

Table 1 Classification criterions for polluted index of soil environmental quality

<table>
<thead>
<tr>
<th>Grade</th>
<th>Synthetical index</th>
<th>Appraisal result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( P_n \leq 0.7 )</td>
<td>Safety domain</td>
</tr>
<tr>
<td>2</td>
<td>( 0.7 &lt; P_n \leq 1.0 )</td>
<td>Precaution domain</td>
</tr>
<tr>
<td>3</td>
<td>( 1.0 &lt; P_n \leq 2.0 )</td>
<td>Slightly polluted domain</td>
</tr>
<tr>
<td>4</td>
<td>( 2.0 &lt; P_n \leq 3.0 )</td>
<td>Moderately polluted domain</td>
</tr>
<tr>
<td>5</td>
<td>( P_n &gt; 3.0 )</td>
<td>Seriously polluted domain</td>
</tr>
</tbody>
</table>

Inverse distance weighted (IDW) interpolation method is based on a basic principle of geography, that things close to one another are more alike. IDW is often used to create a continuous surface from sampled point values. Using Spatial Analyst Module of ArcGIS software (ESRI, 2001), in current study, the assessment map of soil environmental quality was generated from all sampled points with Nemerow’s synthetical pollution index.

Moreover, in order to investigate the soil environmental quality of different districts and primary elements in the agricultural soil, the all the data were evaluated by means of principle component analysis (PCA). PCA was a multivariate analysis technique used to describe the interrelationships among many correlated variables in terms of a few underlying factors (Werner et al., 2003).

Ten indices, including \( P_{xx} \), \( P_{sx} \), \( P_{xs} \), first quantile (\( Q_1 \)), third quantile (\( Q_3 \)), 90% quantile (\( Q_{90} \)), minimum (Min), maximum (Max), percentage of above the precaution (\( P_1 \))

Fig. 1 Location map of soil samples in Zhejiang Province.
and percentage of above the allowed limits (\(P_2\)), were calculated respectively as input parameters for PCA method. 

\[ P_m = \sqrt{\frac{\text{Max}(P_{nj})^2 + P_{nj}^2}{\text{mean}}^2} \]  

where \(P_{nj}\) is the Nemerow’s synthetical pollution index at the \(j\)th sampling point, and Max(\(P_{nj}\)) and \(P_{nj}\) is the maximum and average value of the Nemerow’s synthetical pollution index for all samples.

\[ P_s = \sum_{j=1}^{n} \left( \frac{\sum_{i=1}^{m} P_{ij}}{m} \right) / n \]  

Where \(P\) is the pollution indices for one heavy metal at a sampling point (Eq.(2)), \(m\) is the number of soil heavy metal; \(n\) is the number of the assessing soil samples. 

\(Q_1\), \(Q_3\) and \(Q_{0.9}\) are statistical results according to the Nemerow’s synthetical pollution index of soil samples in each district. \(P_1\) is the percentage of soil samples with \(P_{nj} \geq 0.7\) and \(P_2\) is the percentage of soil samples with \(P_{nj} > 1\) of the whole assessing samples, respectively. A new set of uncorrelated variables called the principal components (PCs) are created from ten above indices using PCA method to analyze the primary pollutants to soils.

### 2 Results and discussion

#### 2.1 Heavy metal concentrations in agricultural soils

Descriptive statistics of concentration of eight heavy metals (Cd, Cr, Pb, Hg, Cu, Zn, Ni and As) are summarized in Table 2. Based on the Standards for Soil Environmental Quality of China (NSPRC, 1995), the allowed values for these heavy metals are listed in Table 2 when soil pH value was more than 6.5 and less than 7.5, and the average value for soil pH in this study was 6.78, which just fell in this scope. As shown in the table, the average concentrations of Cd, Cr, Pb, Hg, Cu, Zn, Ni and As were all below the allowed values of above-mentioned standards. With respect to the total percentage (\(T_1\)) of above this allowed limits, contamination of Cd was the highest, which reached 10.72%, followed by Ni, Hg, Pb, Cu and Cr, contamination of As and Zn was the lowest, which were 1.82% and 1.04%, respectively. Large coefficient of variation (CV) of Hg, Ni and Cd in all soils, which reached 89.06%, 83.66% and 80.9% respectively, implied a great heterogeneity in soils. Otherwise, the variance of Cr was relatively smoother due to its lowest CV value.

An attempt had been made to compare the content of heavy metals given by general soil survey of Zhejiang Province which had been investigated in the 1980s (Table 3), the maximum and minimum values of these eight heavy metals were higher in the present study. Moreover, the heavy metal contents, except Hg and As, were generally above the contents of the survey in the 1980s, which indicated increased concentrations of these heavy metals during the past two decades. It was noteworthy that the maximum of Pb (348.3 mg/kg) and Ni (410.1 mg/kg) were three times higher than that in the 1980s. The contamination of Pb probably due to the exhaust emissions from vehicle, industrial like metal smeltery and wastewater irrigation, which with a high content of Pb. However, the high content of Ni might be due to parent rock of the province consisted of alluvial deposit of the Yangtze River which contains high Ni only next to the lime rock (Zhejiang Province of General Survey on Soil, 1994).

#### 2.2 Spatial distribution of heavy metal contamination in Zhejiang Province

The assessment map of soil environmental quality is illustrated in Fig.2, which created from the Nemerow’s synthetical pollution indices of all soil sampling points using the Inverse Distance Weighted interpolation method. It should be noticed that the interpolated surface were only generated in 38 counties where soil sampling points were collected. As shown in Fig.2, up to 88.96% of the whole study area belonged to the safety domain, whereas only 0.53% area was moderately polluted and more. Summarized with the whole 908 samples, 503 samples were in the safety domain in which the soils were considered as unpolluted, 272 samples were located in the precaution domain in which heavy metals were accumulated in agricultural soils but below the allowed limits, 105 samples were slightly polluted, 14 samples were moderately polluted and 14 samples were seriously polluted, respectively. In other words, most of the agricultural soils of Zhejiang Province was not contaminated with these heavy metals.

#### 2.3 Environmental quality assessment of agricultural soils

The percentage of the heavy metals above the allowable limits (\(T_1\)) in various soil categories were summarized in Table 2.

<table>
<thead>
<tr>
<th>Heavy metal</th>
<th>Agricultural soils (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>Mean: 0.20, Median: 0.17, Range: 0.05–2.8, SD: 0.17, CV (%): 80.9, T1 (%): 10.72, Threshold of second grade: 200^b</td>
</tr>
<tr>
<td>Cr</td>
<td>Mean: 67.29, Median: 64.80, Range: 10.4–324.8, SD: 35.42, CV (%): 52.64, T1 (%): 10.72, Threshold of second grade: 300^a</td>
</tr>
<tr>
<td>Pb</td>
<td>Mean: 33.14, Median: 31.12, Range: 10–348.3, SD: 18.47, CV (%): 55.74, T1 (%): 5.35, Threshold of second grade: 300^a</td>
</tr>
<tr>
<td>Hg</td>
<td>Mean: 0.13, Median: 0.10, Range: 0.02–1.24, SD: 0.12, CV (%): 68.47, T1 (%): 6.80, Threshold of second grade: 300^a</td>
</tr>
<tr>
<td>Cu</td>
<td>Mean: 27.88, Median: 25.19, Range: 10–348.3, SD: 14.84, CV (%): 25.19, T1 (%): 1.04, Threshold of second grade: 300^a</td>
</tr>
<tr>
<td>Zn</td>
<td>Mean: 87.66, Median: 81.50, Range: 28.2–101.9, SD: 47.86, CV (%): 47.86, T1 (%): 8.47, Threshold of second grade: 25^a</td>
</tr>
<tr>
<td>Ni</td>
<td>Mean: 27.14, Median: 24.30, Range: 5–410.1, SD: 22.70, CV (%): 52.64, T1 (%): 9.7, Threshold of second grade: 30^d</td>
</tr>
<tr>
<td>As</td>
<td>Mean: 8.47, Median: 24.30, Range: 1.87–77.33, SD: 7.57, CV (%): 52.64, T1 (%): 1.82, Threshold of second grade: 25^a</td>
</tr>
</tbody>
</table>

CV: coefficient variation; \(T_1\): the total percentage above allowed values; the letters of A, B, C, D represent paddy field, dry land, agricultural land, orchard land, respectively.
in Table 4. $T_1$ value in tea soils descended in the order: Ni>Cr=Cu>Pb>Cd=As>Zn>Hg. Nevertheless, orders of vegetable soils, paddy soils and fruit soils were: Hg>Cd>Ni>Cr>Pb>As>Zn, Ni>Cd>Hg>Pb>Cu>Zn=As>Cr and Cd>Pb>Hg>Ni>Cr>As>Zn>Cu, respectively. $T_1$ value of Cd was placed first rank in fruit soils and second rank in vegetable and paddy soils among the eight metals. $T_1$ values of Zn in four soil categories were relatively lower and less than 1.5%. It was evident that the Cd concentration was apparently influenced by human activities, such as spent litter, Cd-containing phosphorus fertilizers and pesticides, which contain high content of Cd (Chen et al., 1997).

Moreover, ten indices and the PCs scoring of four soil categories were calculated in Tables 5 and 6. As shown in the sorting of PCA analysis, environmental quality of tea soils was better than the other three types of soil, because majority of the tea soils in Zhejiang Province was located in mountain area with a good environmental conditions and lower human impacts. Paddy soils were worse in environmental quality than others, which might originate form extensive agricultural practices, such as applications of pesticides, animal manures and fertilizers. It was confirmed by $P_1$ value in Table 5, that 65.9% of paddy soil samples belonged to precaution domain ($0.7<P_n\leq1.0$) according to GB15618-1995 (Table 1).

### 3 Conclusions

The agricultural soils in Zhejiang Province had a trend of increasing heavy metal concentration compared with previous survey result, which possibly attributed to atmospheric deposition by sedimentation, wastewater irrigation, using of fertilizer and pesticide and might be relate to the parent rock. This research indicated that environmental quality of agricultural soils in Zhejiang Province had degenerated compared with that in the 1980s, which would pollute the food and harm human health to some extent. By utilizing the Nemerow’s synthetical pollution index, coupled with Inverse Distance Weighted interpolation method, the agricultural soil environmental quality was assessed. It revealed that 775 samples were in the safety
domain and 133 samples were slightly polluted and more respectively, which about 14.65% of soil samples had the heavy metal concentration above the threshold levels in whole province, contamination of Cd was the highest, while the contamination of As and Zn was lower. According to the assessment map of soil environmental quality, up to 88.96% of the whole study area was belonged to safety domain, whereas only 0.53% area was moderately polluted and more.

From the results of PCA analysis, it was clearly shown that lower concentrations of heavy metal in the tea soils compared with those of the vegetable soils, fruit soils and paddy soils. It was possibly subjected to the least impact of anthropogenic sources of heavy metals, furthermore, higher concentrations of heavy metals in the paddy soils were strongly influenced by high usage of agrochemicals and differences in cultivation method (Gimeno-Garcfa et al., 1996). The results demonstrated that it was necessary to control heavy metal contamination of agricultural soils, thus preventing release of heavy metals from the contaminated soils.

References


