Assessment and Spatial distribution of zinc pollution in agricultural soils of Chaoyang, China

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Abstract

In this paper, we collected 295 soil samples from Chaoyang as the experiment material, then identify the concentration and spatial distribution of zinc (Zn) in agricultural soils on the basis of The integrated pollution index (IPI) and index geoaccumulation (I_{geo}). The concentration of Zn in soils of Chaoyang are from 22.787 to 669.597 mg kg\textsuperscript{-1}, with an average concentration of 107.082 mg·kg\textsuperscript{-1}. And results of the evaluation show that the pollution excess rate is 2.03%, which indicated that most of samples are slightly polluted. Compared two evaluation methods, integrated pollution index focuses on the evaluation of pollution results, the Geo accumulation index method is more accurate and objective.

Keywords: Zinc(Zn); IPI; I_{geo}; Agricultural soil; Chaoyang City

1. Introduction

Human activities have been causing noteworthy increases contents of trace metals to the environment, particularly during the industrial period [1]. Soils may be polluted with heavy metal due to industrial processes, application of sewage sludge, fertilisers and atmospheric deposition. Zinc occurs in natural soils as a result of weathering of the soil parent material, and total Zn contents in soils in average ranges from 40 to 120 mg·kg\textsuperscript{-1} depending on their lithology [2]. Because Zn is an essential nutrient for plants and soils are often deficient in it [3], the Zn content of farmland soils is usually higher than that of natural soils mainly due to the addition of commercial fertilisers, liming materials or manures [4]. In addition, fungicides and pesticides containing Zn also contribute to its presence in agricultural soils [5]. Zn can
accumulate in agricultural soils, achieving values considerably higher than its optimum concentration as a nutrient, and it may be toxic to soil organisms.

Heavy metal contamination of soils is widespread and there is a risk of transfer of toxic and available metals to humans, animals, and agricultural crops. In fact, heavy metals have a significant toxicity for humans, animals, microorganisms and plants [6, 7].

Although trace metal pollution has been extensively studied in the eastern coastal/industrial regions of China [8, 9, 10, 11], little is known about the trace metal pollution in the northwest farmland areas of China. Chaoyang City is the main oil crops and the grains main producing areas of Liaoning Province.

Geographic information system is a computer system which is used widely in different fields, for inputting, storing, querying, analyzing and displaying a large number of geographic data [12]. There are lots of researches in the field of environmental assessment carried out based on GIS [13, 14, 15, 16, 17]. Index of Geoaccumulation (Igeo) which was advanced by German scientist Muller in 1969 presents quantitative indicator in the study of heavy metal pollution of water sediments. Recently, it is widely used to evaluate the heavy metal pollution [18, 19, 20, 21].

According to “Environmental quality standards for soils”(GB 15618-1995), this paper evaluates the Zn pollution state in agricultural soils of Chaoyang City in China with integrated pollution index, and studies the characteristics of the spatial variation about zinc pollution in agricultural soils of Chaoyang City based on GIS technology.

2. Materials and methods

2.1. Sampling and Analysis

In order to obtain representative samples, this study collected 295 agricultural surface soil samples (0-20 cm) with grid method from five districts which are Chaoyang County, Jianping County, Kazuo County, Beipiao City and Lingyuan City, Chaoyang City in Liaoning Province, China by the GPS. Each sample consisted of 10 points, and we took the same weight of 100g per point, then the weight of a soil sample was mixed to 2 kg. Soil samples were air-dried and passed a plastic sieve of 100 mesh. Distribution of sampling sites was shown in Fig. 1.

![Fig. 1. Distribution of sampling sites in the soil.](image-url)
Physical and chemical properties of soil samples were analyzed by soil agricultural chemistry analysis methods. Total zinc was measured with a flame atomic absorption spectrometer.

2.2. Statistical evaluation

The statistical analysis were completed by EXCEL 2003 and graphics were completed by ARCGIS 9.3.

2.3. Evaluation standard and methods

2.3.1. The integrated pollution index method

The evaluation standard used in this paper includes the upper limit of soil environmental background value in Liaoning Province and “Environmental quality standards for soils” (GB 15618-1995). The integrated pollution index is used commonly as a evaluation method at home and abroad, which includes the single factor index and Nemerow integrated index.

1) The single factor index is calculated as:

\[ P_i = \frac{C_i}{S_i} \]  

where, define \( P_i \) as the single pollution index of the heavy metal, \( C_i \) as the measured concentration of the heavy metal (mg·kg\(^{-1}\)), \( S_i \) as the value of the evaluation criteria of the heavy metal (mg·kg\(^{-1}\)), this study is 0.6 mg·kg\(^{-1}\). When \( P_i \leq 1 \), the soil is clean; if \( P_i > 1 \), the soil is polluted by heavy metal. The greater \( P_i \), the more serious pollution.

2) Nemerow integrated pollution index is calculated as:

\[ P_N = \sqrt{\frac{P_{iave}^2 + P_{imax}^2}{2}} \]  

where, \( P_{iave} \) and \( P_{imax} \) are the average pollution index and the largest single pollution index respectively. Define \( P_N \leq 0.7 \) as clean, \( 0.7 < P_N \leq 1 \) as still clean (Warning limit), \( 1 < P_N \leq 2 \) as slight pollution, \( 2 < P_N \leq 3 \) as middle pollution, \( P_N > 3 \) as heavy pollution.

2.3.2. The Geoaccumulation index method

It is especially widely used for evaluation of heavy metal pollution in the study of modern sediments, and is calculated as:

\[ I_{geo} = \log_2 \left( \frac{C_i}{K \cdot B_i} \right) \]  

where, \( C_i \) is the concentration of the heavy metal in the soil (mg·kg\(^{-1}\)), \( K \) is a constant, represents the changes of background value which might be caused by rock movement (general value is 1.5). \( B_i \) is the geochemical background concentration of the heavy metal in the soil (mg·kg\(^{-1}\)). Different \( B_i \) values will result in a greater difference, in this study \( B_i = 0.11 \text{ mg kg}^{-1} \) [22]. According to \( I_{geo} \) values, the pollution has distinguished seven classes, from Class 0 (\( \leq 0 \)) to Class 6 (\( I_{geo} > 5 \)) [23], class 0 to 5, indicate pollution levels from none to very strong, the element content of the highest class 6 may
reach hundreds of times than the background value. The specific classification is shown in Table 1.

Table 1. $I_{geo}$ and classification of pollution degree.

<table>
<thead>
<tr>
<th>$I_{geo}$</th>
<th>Class</th>
<th>Pollution degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤0</td>
<td>0</td>
<td>Clean</td>
</tr>
<tr>
<td>0-1</td>
<td>1</td>
<td>Slight pollution</td>
</tr>
<tr>
<td>1-2</td>
<td>2</td>
<td>Middle pollution</td>
</tr>
<tr>
<td>2-3</td>
<td>3</td>
<td>Mid-strongly pollution</td>
</tr>
<tr>
<td>3-4</td>
<td>4</td>
<td>Strongly pollution</td>
</tr>
<tr>
<td>4-5</td>
<td>5</td>
<td>Strongly-extremely pollution</td>
</tr>
<tr>
<td>&gt;5</td>
<td>6</td>
<td>Extremely pollution</td>
</tr>
</tbody>
</table>

3. Results and analysis

3.1. The content of Zn in the soil

The Zn content in Chaoyang city generally shows upward trend but leveling off gradually (Fig. 2, Table 2). With the result we know the distribution has been rather dispersed, and the variation coefficient is more than 65%. Parts of Zn distribution zones seem significantly different, which is likely owing to the presence of Zn pollution. The Zn content of agricultural soils in Chaoyang City range from 22.787 mg·kg$^{-1}$ (Jianping County) to 669.597 mg·kg$^{-1}$ (Kazuo County), and the mean Zn is 107.082 mg·kg$^{-1}$. The maximum value which has been greater than the secondary standard value (300 mg·kg$^{-1}$) of “Environmental quality standards for soils” (GB 15618-1995), is much more 10 times than the background value (60 mg·kg$^{-1}$)[24], which indicates that Zn accumulation state in the soil is apparent.

Table 2. The concentration of Zn in the soil.

<table>
<thead>
<tr>
<th>Area</th>
<th>Count</th>
<th>Min. (mg·kg$^{-1}$)</th>
<th>Max. (mg·kg$^{-1}$)</th>
<th>Mean (mg·kg$^{-1}$)</th>
<th>S.D.</th>
<th>CV[%]</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chaoyang County</td>
<td>31</td>
<td>28.149</td>
<td>274.087</td>
<td>85.497</td>
<td>56.989</td>
<td>66.656</td>
<td>0.693</td>
<td>1.184</td>
</tr>
<tr>
<td>Jianping County</td>
<td>65</td>
<td>22.787</td>
<td>627.489</td>
<td>91.478</td>
<td>101.030</td>
<td>110.442</td>
<td>3.185</td>
<td>11.861</td>
</tr>
<tr>
<td>Kazuo County</td>
<td>37</td>
<td>33.214</td>
<td>669.597</td>
<td>94.913</td>
<td>112.486</td>
<td>118.515</td>
<td>3.816</td>
<td>15.868</td>
</tr>
<tr>
<td>Beipiao City</td>
<td>29</td>
<td>29.612</td>
<td>573.922</td>
<td>144.955</td>
<td>136.327</td>
<td>94.048</td>
<td>1.761</td>
<td>2.429</td>
</tr>
<tr>
<td>Lingyuan City</td>
<td>133</td>
<td>38.877</td>
<td>509.545</td>
<td>114.866</td>
<td>83.820</td>
<td>72.972</td>
<td>2.454</td>
<td>6.660</td>
</tr>
<tr>
<td>Total</td>
<td>295</td>
<td>22.787</td>
<td>669.597</td>
<td>107.082</td>
<td>96.528</td>
<td>90.144</td>
<td>2.920</td>
<td>9.616</td>
</tr>
</tbody>
</table>

3.2. Analysis of integrated pollution index

The evaluation results of integrated pollution index ($P_N$) are shown in Table 3. According to “environmental quality standards for soils” (GB 15618-1995), there are 6 exceeded points (Kazuo County 3, Jianping County 1, Beipiao City 1, Lingyuan City 1), and the exceeded rate is 2.03%, the highest one is Kazuo County, 8.1%. In the five regions, only Chaoyang County has not been polluted. Based on the
classification of pollution degree. The total $P_N$ is 1.598, which indicates that the pollution degree is slight pollution. The order of pollution degree of Chaoyang City is as follows, Kazuo County > Jianping County > Beipiao City > Lingyuan City > Chaoyang County.

Fig. 2. Frequency distribution of Zn in the soil.

Table 3. The pollution index of Zn in the soil.

<table>
<thead>
<tr>
<th>Area</th>
<th>Monitoring sites</th>
<th>Excess sites</th>
<th>$P_i$ Min.</th>
<th>$P_i$ Mean</th>
<th>$P_i$ Max.</th>
<th>$P_N$</th>
<th>Pollution degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chaoyang County</td>
<td>31</td>
<td>0</td>
<td>0.094</td>
<td>0.285</td>
<td>0.914</td>
<td>0.677</td>
<td>Still clean</td>
</tr>
<tr>
<td>Jianping County</td>
<td>65</td>
<td>1</td>
<td>0.076</td>
<td>0.305</td>
<td>2.092</td>
<td>1.495</td>
<td>Slight pollution</td>
</tr>
<tr>
<td>Kazuo County</td>
<td>37</td>
<td>3</td>
<td>0.111</td>
<td>0.316</td>
<td>2.232</td>
<td>1.594</td>
<td>Slight pollution</td>
</tr>
<tr>
<td>Beipiao City</td>
<td>29</td>
<td>1</td>
<td>0.099</td>
<td>0.483</td>
<td>1.913</td>
<td>1.395</td>
<td>Slight pollution</td>
</tr>
<tr>
<td>Lingyuan City</td>
<td>133</td>
<td>1</td>
<td>0.130</td>
<td>0.383</td>
<td>1.698</td>
<td>1.231</td>
<td>Slight pollution</td>
</tr>
<tr>
<td>Total</td>
<td>295</td>
<td>6</td>
<td>0.076</td>
<td>0.357</td>
<td>2.232</td>
<td>1.598</td>
<td>Slight pollution</td>
</tr>
</tbody>
</table>

3.3. Analysis of $I_{geo}$

The results of $I_{geo}$ are shown in Table 4. The average $I_{geo}$ of Chaoyang City is -0.19 which represents class 0 (still clean). Among the 295 samples, 184 samples belong to class 1, 73 samples belong to class 2, 29 samples belong to class 2, and 9 samples belong to class 3. Anyway the other regions belong to clean level, in addition to a number of monitoring points in Beipiao City and Lingyuan City.

3.4. Comparative analysis of two evaluation methods

There is a difference between the results of the two evaluation methods, integrated pollution index method showing a slight pollution while the $I_{geo}$ method indicates clean. Two factors may contribute to the discrepancy. (1) Different standard values: the former is sensitive to pH, the latter more to
geochemical background value; (2) Different emphatic points: diverse factors have impact on the Zn concentration assessment involving soil organic matter, soil texture, soil Eh. Other factors such as human activity like fertilization and vehicle emission may also have influences on Zn pollution situation.

The pollution measurement shows clean though there is no excess sampling resources and PN is 0.67. We speculate that the largest single pollution index is overemphasized, thus leading to a distorted assessment result. One way to solve the problem is to give average pollution index larger weight.

Table 4. The classification of Zn pollution based on Igeo in the soil.

<table>
<thead>
<tr>
<th>Area</th>
<th>Igeo</th>
<th>Pollution degree</th>
<th>number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Min.</td>
<td>Max.</td>
</tr>
<tr>
<td>Chaoyang County</td>
<td>-0.30</td>
<td>-1.68</td>
<td>1.61</td>
</tr>
<tr>
<td>Jianping County</td>
<td>-0.45</td>
<td>-1.98</td>
<td>2.80</td>
</tr>
<tr>
<td>Kazuo County</td>
<td>-0.34</td>
<td>-1.44</td>
<td>2.90</td>
</tr>
<tr>
<td>Beipiao City</td>
<td>0.22</td>
<td>-1.60</td>
<td>2.67</td>
</tr>
<tr>
<td>Lingyuan City</td>
<td>0.05</td>
<td>-1.21</td>
<td>2.50</td>
</tr>
<tr>
<td>Total</td>
<td>-0.19</td>
<td>-1.98</td>
<td>2.90</td>
</tr>
</tbody>
</table>

4. Conclusions

Zn concentration of soils taken from Chaoyang has an average value of 107.082 mg·kg⁻¹, fluctuating from 22.787 to 669.597 mg·kg⁻¹. The result is higher than the background value. The spatial distribution of Zn is more dispersed and pollution excess rate is 2.03%. On the whole, the pollution is quite slight and the soil environment quality is good. However, improper fertilization and irrigation from the past may cause Zn accumulation in some of the areas. Considering the different results adopting the two different methods, we should set a criteria that can reflex the results more accurately. In this assay, the geoaccumulation index method is more sensitive and objective than integrated pollution index.

References


