Assessment of Heavy Metal Pollution in Soil Around a plastic metal factory in Jiaxing, China

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Abstract: This study takes the soil around a plastic metal factory in Jiaxing as the research object, and measures the wind direction under the northwest wind in the autumn. The Hg, Cd, As, Ni in the soil samples at different horizontal distances and depths (0-30cm) were evaluated by the geoaccumulation index method, the Nemero pollution comprehensive index method and the potential ecological risk index evaluation method. The number of samples with severe pollution levels calculated by the Nemero pollution comprehensive index method accounted for 85.71% of the total. Using the potential ecological risk index evaluation method, it is concluded that the single ecological risk of Cd and Cr is very strong and above, and the samples account for 100% of the total sample. The soil accumulation index method was used to analyze the pollution of heavy metals: Cd>Hg>Ni>Cu>As, Cr>Pb. The results show that the ecological risk assessment results under the combined action of various heavy metals are not optimistic, and the potential ecological risks are extremely heavy.

1. Introduction

With the rapid development of industrialization in China, the soil near most industrial parks has been polluted by heavy metals to varying degrees. This not only seriously jeopardizes the microbes of plants, animals and soils, but also threatens the stability of ecosystems and human safety. At present, the heavy metals that cause pollution in the soil environment in China are mainly biotoxins, including Hg, Cd, Pb, and As. It also includes common elements with certain toxicity, including Zn, Cu, and Co. Because heavy metals cannot be decomposed by microorganisms in the soil, in recent years, studies on soil heavy metal pollution and how to repair soil problems and the related soil environmental quality evaluation have attracted more and more attention [1].

To assess the heavy metal pollution hazards in the soil, the geoaccumulation index method [2-3], the Nemero pollution comprehensive index method [4-5] and the potential ecological risk index method are used [6]. However, because the geoaccumulation index method and the potential ecological risk index method are used, due to the different background value selection, the evaluation results are quite different. Therefore, based on the collection of soil background values and soil risk assessment and screening values in Zhejiang Province, the soil around a plastic metal factory in Jiaxing City is used as the research object to test its soil. Moreover, the Igeo and RI index is used to evaluate soil metal pollution and ecological health risks, in order to obtain more objective and scientific evaluation results of heavy metal pollution.
1.1. Overview of the study area
The plastic metal factory of this research is located in Jiaxing City, northeast of Zhejiang Province. This plastic metal products company mainly produces packaging plastic products. The plastic itself contains chemical components, which react with other substances during the production process, such as producing odors, so the production environment must be ventilated. In addition, exhaust gas is generated in the process of mechanical production, and there are residues and waste water after production, which are production pollution. In order to protect the surrounding soil environment and the health of the surrounding residents, this study selected seven common heavy metal elements such as Hg, Cd, As, Ni, Pb, Cu and Cr for pollution and health risk assessment according to the specific conditions around the plant.

2. Sample collection and processing

2.1. Sampling
The position of the sampling point is recorded by the compass to record the spatial coordinates. The sampling points are mainly distributed in farmland, vegetable plots and riversides. The locations of the sampling points are shown in Figure 1.

![Figure 1. Surrounding Sampling Map of an Plastic metal Products Company in Jiaxing](image)

The sampling of the surface soil is carried out by grid layout, and 0-10 cm samples are collected. According to the site area, a total of 10 points are collected. The soil profile samples are collected in 3 layers of 0-10cm, 10-20cm, 20-30cm, and 3 profiles are sampled. A total of 30 soil samples are collected. Care should be taken to avoid foreign soil layers and newly disturbed soil layers during sampling. After the soil collected at each sampling point is evenly mixed, it is intended to collect 1~2kg into the sampling bag and mark the number. After registration and numbering, it is necessary to go through processing to retrieve soil samples from the wild.

2.2. Determination of soil samples
After the soil sample to be tested is digested with the plate digestion method, an inductively coupled plasma mass spectrometer (ICP-MS) is used. The soil analysis is carried out by using the national standard method to determine Hg, Cd, As, Ni, Pb, Cu and Cr in the soil constituent elements.

The reagents used in the experiment are all of the excellent purity. The experimental articles used are all soaked in 10% dilute nitric acid for 24 hours and then washed again with ultrapure water. In order to ensure the accuracy of the analysis, blank and parallel samples are made throughout the experiment, and the national standard soil reference material (GSS-1) is added for quality control during the test. The recovery rates of various metals are within the allowable range of national
standard reference materials.

2.3. Heavy metal evaluation method

2.3.1. Nemero pollution comprehensive index method. The Nemero index method is one of the most commonly used methods for calculating the comprehensive pollution index at home and abroad. It first finds the sub-index of each factor, then finds the average value of each sub-index, and finally calculates the maximum sub-index and the average value. In the calculation of pollution load, the single factor pollution index is first calculated based on the measured heavy metal content at a certain point:

\[ P_{ip} = \frac{C_i}{C_{ip}} \]  \hspace{1cm} (1)

Where \( P_{ip} \) is the single pollution index of pollutants \( i \) in the soil; \( C_i \) is the monitoring value of a certain metal; \( C_{ip} \) is the environmental quality standard value, that is, the background value. The Nemero method is a method for comprehensively evaluating heavy metal elements, taking into account the average and maximum values of the single element pollution index. The calculation formula is:

\[ I = \sqrt{\frac{P_{i_{\text{max}}}^2 + \left(\frac{1}{n} \sum P_i\right)^2}{2}} \]  \hspace{1cm} (2)

Where \( I \) is the Nemero comprehensive pollution index; \( P_i \) is the standardized pollution index of the element \( i \) in the soil (single factor index of the contaminant); \( P_{i_{\text{max}}} \) is the maximum of all elemental pollution indices.

The Nemero index not only considers the influence of the most serious pollution factor, but also avoids the subjective factor of determining the weight coefficient. It is one of the most used methods in China for current environmental quality assessment. A general comprehensive pollution index of less than 1 or equal to 1 indicates no pollution, and a value larger than 1 indicates that it has been contaminated. The greater the comprehensive pollution index (\( I \) value), the more serious the soil pollution. Comprehensive classification table of the value \( P \) can be seen in Table 1.

| Pollution Index | Pollution Level | Degree of pollution | Pollution Level |
|-----------------|----------------|---------------------|----------------|
| \( P_{\text{synthesis}} \leq 0.7 \) | 1 | Safety | Clean |
| 0.7 < \( P_{\text{synthesis}} \leq 1 \) | 2 | Alert level | Still clean |
| \( 1 < P_{\text{synthesis}} \leq 2 \) | 3 | Light pollution | Soil lightly polluted crops begin to be polluted |
| \( 2 < P_{\text{synthesis}} \leq 3 \) | 4 | Medium pollution | Soil crops are moderately polluted |
| \( P_{\text{synthesis}} > 3 \) | 5 | Heavy pollution | Soil crops are already polluted |

2.3.2. Geoaccumulation index method (\( I_{\text{geo}} \)). The geoaccumulation index method (\( I_{\text{geo}} \)) is proposed by the German scientist Muller in 1969 and is a quantitative evaluation method for studying the degree of pollution of heavy metals in sediments. It not only reflects the distribution characteristics of heavy metals in sediments, but also intuitively determines the impact of human activities on the environment. Besides, it has been widely used by domestic and foreign scholars to evaluate the heavy metal pollution in soil in recent years. The calculation formula is:
\[ I_{geo} = \log_2 \left( \frac{C_n}{K \times B_n} \right) \] (3)

Where \( C_n \) is the measured value of a certain heavy metal content in the sample, the unit is mg/kg; \( B_n \) is the environmental background value of heavy metal elements (using the heavy metal background value of Zhejiang Province); \( K \) is the fluctuation of the background value that may be caused by the rock forming movement, which is generally taken as 1.5. The relationship between the range of \( I_{geo} \) and heavy metal pollution is shown in Table 2.

| \( I_{geo} \) level | Pollution level          |
|---------------------|--------------------------|
| \( I_{geo} \leq 0 \) | No pollution             |
| \( 0 < I_{geo} \leq 1 \) | Mild pollution          |
| \( 1 < I_{geo} \leq 2 \) | Moderately moderate pollution |
| \( 2 < I_{geo} \leq 3 \) | Moderately polluted     |
| \( 3 < I_{geo} \leq 4 \) | Partial pollution       |
| \( 4 < I_{geo} \leq 5 \) | Severe pollution        |
| \( I_{geo} > 5 \)   | Extremely heavy pollution |

### 2.3.3. Potential ecological risk index evaluation method.

The potential ecological risk index evaluation method proposed by Swedish scholar Hakanson in 1980 is a relatively fast, simple and standard method for dividing the pollution level of pollutants and its potential ecological risks. The potential ecological risk index can be calculated by measuring the content of pollutants in the sample, which is enabled to reflect the heavy metal content and toxicity in the soil.

\[ C_j = \frac{C_{ij}}{C_R} \quad E_j = T_i \times C_j \quad RI = \sum_{i=1}^{n} E_i \] (4)

Where \( C_j \) is the pollution parameter of a certain metal; \( C_{ij} \) is the measured content of heavy metals in the pollutant; \( C_R \) is the reference value required for the calculation; \( E_j \) is the potential ecological risk parameter; \( T_i \) is the toxicity response parameter of the individual pollutant; \( RI \) is the potential ecological risk index for multiple metals. The background value of heavy metals and its toxicity coefficient are shown in Table 3.

| Heavy metal | Cd (mg/kg) | Hg (mg/kg) | Pb (mg/kg) | As (mg/kg) | Ni (mg/kg) | Cr (mg/kg) | Cu (mg/kg) |
|-------------|------------|------------|------------|------------|------------|------------|------------|
| Background values \( C_{ni} \) | 0.206 | 0.247 | 38.2 | 10 | 41.1 | 92.1 | 40.8 |
| Toxicity coefficient \( T_i \) | 30 | 40 | 5 | 10 | 5 | 2 | 5 |

### 3. Statistical description of basic parameters of heavy metals in soil

#### Table 4. Heavy metal content of surface soil (10-30cm)

| Examination range /mg·kg⁻¹ | 9.68-25.39 | 0.31-11.16 | 15.99-30.89 | 2.12-12.94 | 42.02-69.66 | 103.22-168.36 |
|----------------------------|------------|------------|------------|------------|------------|------------|
| Average value /mg·kg⁻¹      | 15.93      | 3.17       | 20.53      | 8.99       | 46.43      | 120.42     |
| Coefficient of variation /% | 29.4       | 89.9       | 21.9       | 33.8       | 47.3       | 12.4       |
| Excess rate /%              | 100        | 100        | 0          | 0          | 100        | 0          |
| Average over multiple       | 52.1       | 9.57       | 0          | 0          | 0.16       | 0          |
In this paper, from the overall data analysis and the current status of Table 4 distribution, there is no regularity in the horizontal and vertical distribution of various heavy metal elements in the soil at 30 sampling points. Also, a large amount of data is also difficult to derive the distribution of heavy metal elements in the region. In the study area, the overall concentration values of Pb and As elements in the sampling point are very normal, and the average over-standard value and over-standard rate are both 0, which is in a extremely low concentration and a very safe state. In the surface soil, the metal element Cu appears to be extremely small in individual scale, which is not very serious. The coefficient of variation of the seven heavy metals is in the order of Cr<Pb<Cd<Cu<As<Ni<Hg. The results are similar to those of Li Yumei’s soil heavy metal pollution and health risk assessment around the aluminum plant in Baotou. The coefficient of variation of the six heavy metals tested in the aluminum plant is from small to large, Ni<Cd<Zn<Pb<Cr<Cu. Among them, the coefficient of variation of Hg reaches 89.9%, which is a strong mutation. It can be seen that the content of Hg is particularly affected by human activities. Except for Cd, Pb and Cr, the coefficient of variation of the other four elements exceeds 30%. Therefore, by observing the data in the above table, it can be found that the larger the coefficient of variation, the deeper the influence of human activities on the content of heavy metals. If the coefficient of variation exceeds 30%, it indicates that such metals are already heavily affected by human influence.

After comparison, the surface soils Cd, Hg, and Ni of the plastic metal factory greatly exceed the standard value limits of various elements specified in the secondary standard of the Soil Environmental Quality Standard (GB 15618-1995) at any sampling point. The average excess multiples are respectively 52.1, 9.57 and 0.16 times. The 2Cd concentration of the most polluted sampling point is 30.89mg/kg, which is 474 times higher than the background value and 101 times higher than the standard value. The over-standard rate and coefficient of variation of Cd are at a high level, which can be seen to be very serious. Compared with other industries, the pollution of this plastic metal factory is mainly concentrated on the pollution of Cd and Hg.

### 3.1. Sample contamination level

The Nemero pollution comprehensive index method is used to calculate the pollution levels under the combined action of various heavy metals. It is found in these seven metals that the Nemero comprehensive pollution index of Pb is 0.91, indicating that it is not contaminated. The Nemero pollution index of As, Cu, Ni, Cr, Hg, and Cd is all higher than 1, indicating that it has been contaminated. However, Cd and Hg are respectively 276.21 and 114.37, indicating that soil pollution is very serious. The comprehensive classification of P values is shown in Table 5.

| Heavy metal | Nemero Comprehensive Pollution Index | Sample ratio /% |
|-------------|-------------------------------------|-----------------|
| Pb          | 0.91                                | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
| As          | 1.08                                | 23.33   | 53.33   | 23.33   | 0       | 0       |
| Hg          | 114.37                              | 0       | 3.33    | 3.33    | 0       | 93.34   |
| Cu          | 1.98                                | 0       | 13.33   | 66.67   | 20      | 0       |
| Ni          | 2.31                                | 10      | 10      | 53.33   | 0       | 6.67    |
| Cr          | 2.18                                | 0       | 0       | 20      | 76.67   | 3.33    |
| Cd          | 276.21                              | 0       | 0       | 0       | 0       | 100     |

### 3.2. Geoaccumulation index method

According to the survey situation and sample analysis data, the geoaccumulation index method is used to analyze the pollution status and pollution degree of various heavy metals. The soil element
background value in Zhejiang Province is selected as the reference value of the region to study whether there are certain rules through data research. It can be seen from Table 6 that Cd reaches extremely heavy pollution in the heavy metals around the plastic metal factory, and Hg reaches heavy pollution. The order of pollution from strong to weak is Cd>Hg>Cu>Ni>Pb>As. The results are similar to the results of heavy metal pollution and risk assessment of soil around Zhongshan Industrial Park by Yu Shujie. The Igeo value of Cd is the largest, indicating that the Igeo value of Cd in the soil sample is more discrete. That is to say, the degree of variation is larger and the degree of pollution is more serious.

As the soil depth increases, Cd and Hg do not show any regularity in the content. At 0-10 cm, Cr is slightly polluted, and Ni and Cu also have some light pollution at some points. The average value of the geaccumulation index of the remaining heavy metal elements is less than 0, and the overall level is at a non-polluting level. Besides, the change in content has no obvious regularity in the longitudinal direction. The severity of both types of heavy metal pollution is deepening as soil depth increases. There is slight contamination of Cr at 10-20 cm and 20-30 cm. The content of heavy metals does not show a specific law in the longitudinal distribution, and the average value of the cumulative index of the remaining heavy metals is below 0, which is at a non-polluting level. It can be seen that the surrounding soil has a heavy mixed pollution of Cd and Hg, and a slight partial pollution of Cr, Cu and Ni.

The above analysis shows that the actual measurement results of a plastic metal factory in Jiaxing City in this survey are geaccumulatively evaluated. It is understood that the vertical distribution of heavy metal elements in the surrounding soil of the factory has no special circumstances and there is no certain correlation law.

| Heavy metal | Ground accumulation index Igeo | Level 0 | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 | Sample ratio % |
|-------------|--------------------------------|--------|--------|--------|--------|--------|--------|--------|---------------|
| Pb          | -0.843                         | 100    | 0      | 0      | 0      | 0      | 0      | 0      | 0             |
| As          | -0.87                          | 96.67  | 3.33   | 0      | 0      | 0      | 0      | 0      | 0             |
| Hg          | 4.198                          | 3.33   | 3.33   | 6.67   | 6.67   | 13.34  | 33.33  | 33.33  | 33.33         |
| Cu          | 0.0184                         | 53.33  | 46.67  | 0      | 0      | 0      | 0      | 0      | 0             |
| Ni          | -0.194                         | 40     | 53.33  | 6.67   | 0      | 0      | 0      | 0      | 0             |
| Cr          | 0.548                          | 0      | 96.67  | 3.33   | 0      | 0      | 0      | 0      | 0             |
| Cd          | 7.286                          | 0      | 0      | 0      | 0      | 0      | 0      | 100    | 0             |

3.3. Potential ecological risk factors and indices for individual elements

3.3.1. Evaluation of pollution degree. The potential ecological risk index evaluation method proposed by Haknson is used to assess the potential ecological risk of the sample collection area. Because of the high contamination rate of Cd and Hg in the sample, it is used as the key type of heavy metal to evaluate its single factor ecological risk. Figure 2 shows the spatial variation of soil heavy metal pollution coefficient around a plastic metal factory in Jiaxing. The change of Cd with the point is the largest, while the change trend of Pb and As is relatively flat, which means that the content of these two heavy metals is relatively uniform in the region. The single potential ecological risk index of Cd is 390.61. This is much higher than the vertical pollution characteristics and risk assessment of heavy metals in soil of Su Yaoming’s polymetallic mining area, which single potential ecological risk index is 77.1. That is to say, attention should be paid to the process of remediation and treatment of heavy metal pollution in the site soil.
3.3.2. Ecological risk assessment. Table 8 shows that there are carcinogenic risks in As, Hg, Cu, Ni, Cd and Cr in the study area. The carcinogenic risk index of As, Hg, Cu, Ni and Cr has exceeded the standard value, which is a very serious risk. Although the carcinogenic risk of Pb is within the acceptable range, it has potential carcinogenicity. The cancer risk health index of Cd has seriously exceeded the warning. The value should be highly valued by the relevant departments. The carcinogenic health risk index of Cd seriously exceeds the warning value and should be highly valued by relevant departments.

| Heavy metal | Maximum | Minimum value | Arithmetic mean | Standard deviation | Slight | Medium | Strong | Very strong | Extremely strong |
|-------------|---------|---------------|----------------|-------------------|-------|--------|--------|------------|-----------------|
| Cd          | 25.39   | 6.56          | 15.93          | 0.289             | 0     | 0      | 0      | 16.67      | 83.33           |
| Hg          | 11.16   | 0.05          | 3.17           | 0.883             | 20    | 23.33  | 26.67  | 23.33      | 0               |
| Pb          | 30.89   | 14.09         | 20.53          | 0.178             | 100   | 0      | 0      | 0          | 0               |
| As          | 15.62   | 2.12          | 8.99           | 0.332             | 3.33  | 36.67  | 60     | 0          | 0               |
| Ni          | 90.27   | 0.26          | 46.43          | 0.465             | 3.33  | 6.67   | 13.33  | 53.34      | 23.33           |
| Cr          | 168.36  | 83.98         | 120.42         | 0.121             | 0     | 0      | 0      | 96.67      | 3.33            |
| Cu          | 58.69   | 15.46         | 33.59          | 0.316             | 3.33  | 0      | 46.67  | 50         |                 |

4. Conclusion

(1) With the help of the geoaccumulation index method, the geoaccumulation index of Pb is 7.286. That is, the contamination rate of As, Cd, Cr, Hg, Cu, and Ni is 90% or more, except that Pb is not contaminated. Their heavy metal pollution is Cd>Hg>Cr>Ni>As>Cu>Pb, indicating that there is no direct relationship between the effects of human activities on the environment.

(2) The Nemero pollution comprehensive index method is used to calculate the pollution level of the urban area under the combined action of heavy metals. The results show that the Nemero pollution indices of As, Cu, Ni, Cr, Hg and Cd are all larger than 1, indicating that they have been contaminated. The number of Cr samples with heavy pollution levels accounts for 76.67% of the total. Among them, the Nemero index of Cd and Hg samples is higher than 50, respectively accounting for 100% and 93.34% of the total sample, indicating extremely heavy soil pollution.

(3) The potential ecological risk index evaluation method is used to analyze the ecological risk level of a single heavy metal and comprehensive ecological risk level in the sample. The results reflect that the single ecological risk of Cd and Cr in soil is extremely strong, and the ecological risk assessment results under the action of multiple heavy metals show extremely serious risks.

(4) The above three evaluation methods are used to analyze the heavy metals in the soil. The results
show that the soil environment around Fumao Plastic Metal Products Co., Ltd. already has serious pollution, which needs to be paid attention to. The later repaired Cd should be the main target of heavy metal pollution to avoid accumulation of damage to the soil ecological environment.

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