**Assessment of Potential Heavy Metal Contamination in the Agricultural Soils based on various improved evaluation methods in Beijing，China**

Supplementary Information

Pages = 10

Tables = 2

Method of Ecological risk assessment

**The improved Hå kanson method calculation method is as follows. (1-3) :**

(1) Hå kanson method basic formula

The pollutants evaluated by Håkanson method include PCB, Hg, Cd, As, Pb, Cu, Cr, and Zn. The single-factor ecological risk and the comprehensive ecological risk of pollutants are calculated in equation (1) (2):

(1)

(2)

where is the toxicity response coefficient of pollutant *i*; is the pollution factor of pollutant *i*; is the measured concentration of pollutant *i* in the soil, and is the soil background value of pollutant *i*.

(2) Modified Hå kanson method correction formula

1) Correction of effect factors for toxic response

The "absorption effect" of crops is used to replace the "sedimentation effect" and "sensitivity effect" of the Håkanson method. The heavy metal absorption capacity of crops is taken as the effect factor of the toxicity response, which is defined as the "absorption effect", expressed by δ, and the calculation is shown in formula (3):

(3)

where and are the content of pollutants in the *k-th* crop and the corresponding soil, respectively, and *n* represents the number of sampling points.

Standardize the toxicity response coefficient to ensure that its numerical range matches the range of the pollution factor . Finally, the product of the crop absorption effect coefficient ẟ and the relative abundance number is the modified toxicity response coefficient of each pollutant .

2) Pollutant types-absorption coefficient correction

1. 、 and are 1、20 and 10 respectively；
2. The maximum value of (Max) is the standard limit for low risk classification, and the limits for medium risk, strong risk, and strong risk classification are respectively 2 times, 4 times and 8 times of the low risk standard limit；
3. According to formula (2), the and of *Pb、Cd* and *As* are calculated, and the ten-digit value of is rounded to the whole by the principle of rounding, and rounded to 30, the value is 𝑅𝐼 low Risk standard limit;
4. The grading limits of medium risk and strong risk are 2 times and 4 times of the low risk grading limit respectively.

**Establishment of improved analytic hierarchy process. (4-9) :**

(1) The construction of the judgment matrix and the matrix feature vector

At each level, compare the indicators of the level one by one, quantify them according to the specified scaling method, and write a numerical judgment matrix. According to the specified scaling method, the judgment matrix of A→B level (7), the judgment matrix B1→C (8) and the judgment matrix B2→C (9) are established.

A→B： (4)

B1→C： (5)

B2→C： (6)

(2) Calculate the maximum eigenvalue

Based on the eigenvectors, the algorithm of the maximum eigenvalue λmax is as follows:

(7)

where W is the eigenvector, Wi is the i-th element in the eigenvector, C is the judgment matrix, and n is the order of the judgment matrix.

(3) Consistency inspection

According to the constructed judgment matrix, calculate the weight of all factors related to this level for a factor of the upper level. In order to measure the degree of deviation of the judgment matrix from the consistency, the negative average CI of the remaining characteristic roots other than the maximum eigenvalue of the judgment matrix is introduced. The calculation formula is:

(8)

In order to measure whether different judgment matrices have satisfactory consistency, the average random consistency index *RI* is introduced. Calculate the random consistency ratio . When CR<0.10, the matrix is considered to have satisfactory consistency, otherwise the judgment matrix must be reconstructed until it has satisfactory consistency.

(9)

In the formula, ai is the weight value of the A-level factors. When CR<0.1, the result of the overall ranking of levels is considered satisfactory. The judgment matrix is calculated according to formula, and the consistency check results of each layer are shown in Table 3.

**Table S1. Consistency inspection indicators at various levels**

|  |  |  |  |
| --- | --- | --- | --- |
| Level | λmax | CI | CR |
| B→A | 2 | 0 | 0 |
| C→B1 | 3 | 0 | 0 |
| C→B2 | 3 | 0 | 0 |

**Establishment of improved weighted average method. (10-12):**

(10)

(11)

where Pi is the pollution factor of a certain pollutant, ci is the measured average content of a certain pollutant( mg·kg-1), Si is the reference value of a certain pollutant( mg·kg-1), Wi is the weight of a certain heavy metal element Weight (here the weight is calculated by the analytic hierarchy process), P is the comprehensive pollution index. This paper uses the weighting method to determine the value of Si.

Comprehensive evaluation

(12)

Grade judgment standard: P≤0.2 is clean grade, 0.2＜P≤0.9 is light pollution grade, 0.9＜P≤1.6 is moderate pollution grade, and P>1.6 is heavy pollution grade.

**Soil and Agricultural Products Influence index of comprehensive quality mainly include the following calculation processes. (13-19):**

(1) Determine the pollution elements and quantity

Index discriminant method: compare the measured values of the elements in soil samples with the evaluation standard values and background values to confirm the X and Y values of the number of soil samples exceeding the standard values and background values; compare the measured values of the elements in agricultural samples with the limit standards for contaminants in food In order to confirm the Z value of the number of agricultural products samples exceeding the pollutant limit standard, a relatively simple method can be used to determine the index.

(2) Relative impact equivalent (RIE)

(13)

Where N is the number of elements to be measured, Ci is the concentration of element i, Csi is the soil environmental quality standard value (evaluation reference value) of element i, and n is the oxidation number of element i. The larger the RIE value, the more obvious the influence of foreign substances.

(3) Deviation degree of determination concentration from the background value (DDDB)

(14)

where CBi is the background value of element i, and the other symbols have the same meaning as above. The larger the DDDB, the more obvious the influence of foreign substances.

(4) Deviation degree of soil standard from the background value (DDSB)

(15)

where the larger the DDSB, the greater the deviation of the soil standard from the background value, the greater the load capacity of the specific soil, and the stronger the buffering of foreign substances.

(5) Quality index of agricultural products (QIAP)

(16)

Where CAPi is the concentration of element i in agricultural products at the corresponding point in the soil, and CLSi is the limit standard for element i in agricultural products (pollutant limit standard; hygiene standard). The value of QIAP indicates the status of the impact of heavy metals on the quality of agricultural products. When the concentration of heavy metals in agricultural products exceeds the pollutant limit standard, the larger the value, the worse the quality.

(6) Construct an integrated quality impact index (IICQ)

(17)

(18)

(19)

Where X and Y are the number of soil measurement values exceeding the standard value and background value, respectively; Z is the number of elements in the agricultural product that exceed the pollutant limit standard, and k is the background correction factor, which is related to the national standard and element background of the agricultural product pollutant limit. The parameter related to the ratio of values (k =5).

**Table S2.**

**Calculation results of various parameters in the evaluation**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Fang  shan | Sample serial number | Soil sample | | | | Agricultural products | | Soil exceeding standard  X | Soil super background  Y | Excess agricultural products  Z | Comprehensive  IICQ |
| RIE | DDDB | DDSB | IICQS | QIAP | IICQAP |
| 1 | 0.678 | 0.994 | 4.453 | 0.447 | 0.065 | 0.058 | 0 | 2 | 0 | 0.504 |
| 2 | 0.702 | 1.039 | 4.453 | 0.467 | 0.293 | 0.013 | 0 | 2 | 0 | 0.48 |
| 3 | 0.8 | 1.211 | 4.453 | 0.544 | 0.482 | 0.022 | 0 | 2 | 0 | 0.566 |
| IICQ | 0.517±0.036 | | | | | | | | | |
| Da  xing | Sample serial number | Soil sample | | | | Agricultural products | | Soil exceeding standard  X | Soil super background  Y | Excess agricultural products  Z | Comprehensive  IICQ |
| RIE | DDDB | DDSB | IICQS | QIAP | IICQAP |
| 1 | 0.676 | 0.969 | 4.453 | 0.218 | 0.35 | 0.016 | 0 | 1 | 0 | 0.233 |
| 2 | 0.79 | 1.078 | 4.453 | 0.484 | 0.651 | 0.029 | 0 | 2 | 0 | 0.513 |
| 3 | 0.798 | 1.145 | 4.453 | 0.771 | 0.802 | 0.036 | 0 | 3 | 0 | 0.807 |
| IICQ | 0.518±0.234 | | | | | | | | | |
| Shun  yi | Sample serial number | Soil sample | | | | Agricultural products | | Soil exceeding standard  X | Soil super background  Y | Excess agricultural products  Z | Comprehensive  IICQ |
| RIE | DDDB | DDSB | IICQS | QIAP | IICQAP |
| 1 | 0.676 | 0.969 | 4.453 | 0.218 | 0.511 | 0.023 | 0 | 1 | 0 | 0.241 |
| 2 | 0.79 | 1.143 | 4.453 | 0.513 | 0.671 | 0.03 | 0 | 2 | 0 | 0.544 |
| 3 | 0.798 | 1.157 | 4.453 | 0.52 | 0.795 | 0.036 | 0 | 2 | 0 | 0.556 |
| IICQ | 0.447±0.146 | | | | | | | | | |
| Shi  Jing  shan | Sample serial number | Soil sample | | | | Agricultural products | | Soil exceeding standard  X | Soil super background  Y | Excess agricultural products  Z | Comprehensive  IICQ |
| RIE | DDDB | DDSB | IICQS | QIAP | IICQAP |
| 1 | 0.762 | 0.919 | 4.453 | 0.206 | 0.335 | 0.015 | 0 | 1 | 0 | 0.221 |
| 2 | 0.8 | 1.148 | 4.453 | 0.774 | 0.583 | 0.026 | 0 | 3 | 0 | 0.8 |
| 3 | 0.847 | 1.221 | 4.453 | 0.823 | 0.711 | 0.032 | 0 | 3 | 0 | 0.855 |
| IICQ | 0.625±0.287 | | | | | | | | | |
| Men  Tou  gou | Sample serial number | Soil sample | | | | Agricultural products | | Soil exceeding standard  X | Soil super background  Y | Excess agricultural products  Z | Comprehensive  IICQ |
| RIE | DDDB | DDSB | IICQS | QIAP | IICQAP |
| 1 | 0.672 | 0.958 | 4.453 | 0.215 | 0.372 | 0.017 | 0 | 1 | 0 | 0.232 |
| 2 | 0.819 | 1.184 | 4.453 | 0.797 | 0.608 | 0.027 | 0 | 3 | 0 | 0.825 |
| 3 | 0.829 | 1.199 | 4.453 | 0.808 | 0.728 | 0.033 | 0 | 3 | 0 | 0.841 |
| IICQ | 0.632±0.283 | | | | | | | | | |
| Chang  ping | Sample serial number | Soil sample | | | | Agricultural products | | Soil exceeding standard  X | Soil super background  Y | Excess agricultural products  Z | Comprehensive  IICQ |
| RIE | DDDB | DDSB | IICQS | QIAP | IICQAP |
| 1 | 0.652 | 0.931 | 4.453 | 0.209 | 0.357 | 0.016 | 0 | 1 | 0 | 0.225 |
| 2 | 0.787 | 1.139 | 4.453 | 0.511 | 0.676 | 0.03 | 0 | 2 | 0 | 0.542 |
| 3 | 0.801 | 1.161 | 4.453 | 0.521 | 0.852 | 0.038 | 0 | 2 | 0 | 0.559 |
| IICQ | 0.442±0.154 | | | | | | | | | |
| Mi  yun | Sample serial number | Soil sample | | | | Agricultural products | | Soil exceeding standard  X | Soil super background  Y | Excess agricultural products  Z | Comprehensive  IICQ |
| RIE | DDDB | DDSB | IICQS | QIAP | IICQAP |
| 1 | 0.636 | 0.916 | 4.453 | 0.206 | 0.361 | 0.016 | 0 | 1 | 0 | 0.222 |
| 2 | 0.714 | 1.026 | 4.453 | 0.461 | 0.56 | 0.025 | 0 | 2 | 0 | 0.486 |
| 3 | 0.803 | 1.159 | 4.453 | 0.781 | 0.656 | 0.029 | 0 | 3 | 0 | 0.81 |
| IICQ | 0.506±0.241 | | | | | | | | | |
| Huai  rou | Sample serial number | Soil sample | | | | Agricultural products | | Soil exceeding standard  X | Soil super background  Y | Excess agricultural products  Z | Comprehensive  IICQ |
| RIE | DDDB | DDSB | IICQS | QIAP | IICQAP |
| 1 | 0.648 | 0.937 | 4.453 | 0.21 | 0.31 | 0.014 | 0 | 1 | 0 | 0.224 |
| 2 | 0.752 | 1.094 | 4.453 | 0.491 | 0.551 | 0.025 | 0 | 2 | 0 | 0.516 |
| 3 | 0.779 | 1.126 | 4.453 | 0.506 | 0.75 | 0.034 | 0 | 2 | 0 | 0.539 |
| IICQ | 0.427±0.143 | | | | | | | | | |

**Reurence**

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