Analysis and Evaluation of Heavy Metal Pollution of Surface Soil in Baicheng City Based on Factor Analysis Method

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Abstract. In the thesis, the pollution condition of heavy metals in the soil is evaluated by fuzzy comprehensive evaluation method through testing and analyzing content of heavy metals (As Cd Cr Cu Hg Ni Pb Zn) in 400 sampling points within $400km^2$ near Baicheng City; and types and sources of pollutions of heavy metals in the soil in Baicheng City are analyzed and studied by factor analysis method. scientific proof for soil improvement and phytoremediation in this area can be provided. It is indicated through the integrated evaluation of the test result that the living quarter, the main road area and the green belt are polluted slightly; the industrial area is polluted moderately. It can be seen through comprehensive analysis that there are three main sources of heavy metal pollutions in the surface soil in Baicheng City: industrial pollution source, traffic pollution source and house pollution source. Therefore, effective measures shall be taken by the local people in the protection of the soil encountered with the various pollution status of the functional areas.

Introduction

Along with fast promotion of industrialization and urbanization, lots of wastes generated from industry, traffic and business enter into soil; while penetrating into soil, pollutants with various heavy metals can pose danger to human health through several ways such as food chain and even induce diseases such as cancer[1]. Pollution of heavy metals to soil is irreverse, therefore, real-time analysis of content of heavy metals and taking preventative measures are very important for protecting the soil. In the research, the author analyzes pollution of heavy metals in soil and its sources and distribution based on Baicheng City and its surrounding areas, aiming at confirming conditions and distribution features of heavy metals in soil in the urban area and offering scientific basis to treating soil pollutions and ecological restoration.

Sample Collection and Division of Functional Zone

Divide Baicheng City into gridding areas with a distance of about 1km; sample and number the surface soil (0～20cm thick) at each sampling points every $1km^2$ and record the position of the sampling point by GPS. Conduct test and analysis by special instruments; then acquire the basis of thickness of various chemical elements contained in each sample. In addition, take samples in a natural area far away from crowds and industrial activities with a space of 2km and regard them as the background value of elements in the surface soil in Baicheng City.

According to actual situations of Baicheng City, divide the urban area into the living quarter, the industrial area, the main road area and the green belt recorded as class 1, class 2, class 3 and class 4; human activities pose different influences upon the environment in different areas.

Integrated Evaluation of Pollution Level of Heavy Metal in Soil

Evaluation standard.

National Soil Environment Standard [2], Soil environmental background value in Baicheng City (see table 1), the evaluation standard drafted by Shu Dongni [3] (see table 3) and integrated evaluation grading standard for heavy metal pollution in soil offered by Zhang Chaolan [4] (see

table 2) are applied in the research.

Table 1 Background value of 8 metal elements in Baicheng City

Element	Average value	Standard deviation	Scope
As （μg/g）	3.6	0.9	1.8～5.4
Cd （ng/g）	130	30	70～190
Cr （μg/g）	31	9	13～49
Cu （μg/g）	13.2	3.6	6.0～20.4
Hg （ng/g）	35	8	19～51
Ni （μg/g）	12.3	3.8	4.7～19.9
Pb （μg/g）	31	6	19～43
Zn （μg/g）	69	14	41～97

Table 2 Grade of integrated evaluation standard for heavy metal pollution in soil

Grade	I	II	III	IV	V
V_j	10	20	30	40	50
Approach degree （V_0/V_j)	1	0.5	0.33	0.25	0.20
Evaluation standard	1.00	≥0.50	≥0.33	≥0.25	≥0.20
Pollution level	A	B	C	D	E

A, B, C, D, E represents extremely clean, clean, slight pollution, moderate pollution and heavy pollution. Similarly hereinafter.

Table 3 Grading standard for heavy metal pollution in soil

Grade / Heavy metal	5	4	3	2	1
As(μg/g)	≤3.6	≤5.4	≤6.3	≤7.2	＞7.2
Cd(ng/g)	≤130	≤190	≤220	≤250	＞250
Cr(μg/g)	≤31	≤49	≤58	≤67	＞67
Cu(μg/g)	≤13.2	≤20.4	≤24	≤27.6	＞27.6
Hg(ng/g)	≤35	≤51	≤59	≤67	＞67
Ni(μg/g)	≤12.3	≤19.9	≤23.7	≤27.5	＞27.5
Pb(μg/g)	≤31	≤43	≤49	≤55	＞55
Zn(μg/g)	≤69	≤97	≤111	≤125	＞125
Pollution level	A	B	C	D	E

Evaluation method.

Fuzzy comprehensive evaluation method[4] is applied in the thesis to evaluate pollution condition of heavy metals in soil; first, the weight value α_j of each factor is calculated, and the sum of weight values is calculated according to $\sum_{j=1}^{m} \alpha_j$; then the weight coefficient of each factor can be calculated by the formula $\alpha_j = 10 a_j / \sum_{j=1}^{m} \alpha_j$. The result is listed in table 4.

Table 4 weight coefficient of heavy metals in soil in Baicheng City

	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Weight in class 1	0.0882	0.1129	0.1127	0.1894	0.1364	0.0755	0.1129	0.1739
Weight in class 2	0.0464	0.0697	0.0397	0.2225	0.4227	0.0371	0.0691	0.0928
Weight in class 3	0.0517	0.0902	0.061	0.1535	0.4157	0.0466	0.0667	0.1146
Weight in class 4	0.1066	0.1323	0.0863	0.1402	0.2014	0.0762	0.12	0.137

In order to calculate the approach degree of the evaluation standard, we should calculate the variable value of the index $u_{ij} = X_{ij}\alpha_j$ (X_{ij} is the score of index variable j of sample i and α_j is weight coefficient of sample j.) Then, calculate the sum of index variables $V_i = \sum_{j=1}^{m} u_{ij}$ and the sum of variables of samples contrasted with the standard $V_0 = \sum_{j=1}^{m} x_{0j}\alpha_j$ (X_{0j} is the standard grade in the formula, and is class I of clean, namely $X_{0j} = 1$); finally calculate the approach degree $N_i = \dfrac{V_0}{V_j}$.

Integrated valuation.

According to the approach degree, heavy metal pollution in soil in 4 areas in Baicheng City can be evaluated comprehensively by the integrated evaluation grading standard for heavy metal pollutions in soil in table 2; the result can be seen in table 5.

Table 5 Integrated evaluation of heavy metal pollution in soil in Baicheng City

Area	Living quarter	Industrial area	Main road area	Green belt
Approach degree	0.3358	0.2773	0.352	0.3907
Pollution level	C	D	C	C

Analysis of Source of Heavy Metal Pollution in Soil

Analysis method.

In order to analyze source of heavy metal pollution in soil, the method [5][6] in the article Main Sources of Heavy Metal Pollutions in Soil in Taiyuan City Based on Factor Analysis Method is applied as the following steps:

(1) Standardization of the original data; the formula is $X_{ij} - X_j / \delta_j$, in which X_{ij} is the index value j of sample i; while X_j and δ_j are the average value and the standard deviation of index j. It aims at eliminating influences of dimensions of different variables; however, conversion of standardization will not change relevant coefficients of variables.

(2) Calculate relevant coefficient matrix of standardized data, and proper value and proper vector of the matrix of relevant coefficients.

(3) Use orthogonal transformation and maximum variance method to polarize factor loading; while the factor after revolving is still orthogonal.

(4) Confirm number of factors and calculate their scores for statistical analysis.

Result analysis.

In the thesis, indexes of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn are used for factor analysis by SPSS18.0 statistics software after data standardization processing; then the matrix of relevant coefficients of content of 8 heavy metal elements is acquired. The living quarter is taken as an example to analyze and the result can be seen in table 6.

Table 6 Matrix of relevant coefficients of 8 elements in the living quarter

	As (µg/g)	Cd (ng/g)	Cr (µg/g)	Cu (µg/g)	Hg (ng/g)	Ni (µg/g)	Pb (µg/g)	Zn (µg/g)
As (µg/g)	1	0.381	0.238	0.531	0.293	0.605	0.45	-0.017
Cd (ng/g)	0.328	1	0.349	0.499	0.397	0.283	0.802	0.346
Cr (µg/g)	0.334	0.3	1	0.376	0.15	0.527	0.416	0.412
Cu (µg/g)	0.242	0.34	0.211	1	0.198	0.434	0.502	0.238
Hg (ng/g)	0.238	0.502	0.434	0.198	1	0.211	0.34	0.242
Ni (µg/g)	0.412	0.416	0.527	0.15	0.376	1	0.3	0.334
Pb (µg/g)	0.346	0.802	0.283	0.397	0.499	0.349	1	0.328
Zn (µg/g)	-0.017	0.45	0.605	0.293	0.531	0.238	0.381	1

It can be seen in the above stable that the correlation between Pb and Cd is the best; Zn, Cr, As and Ni is the second; while that between other elements is not good. It can be also seen from factors that elements with good correlation may be relevant in factors and sources.

The key of factor analysis is to calculate feature value and accumulated contribution rate of relevant factors by the matrix of relevant coefficients; those in the living quarter can be seen in table 7.

Table 7 Feature value and accumulated contribution rate of variables in the living quarter

Factor	Before revolving			After revolving		
	Feature value	% of variance	% of accumulated contribution rate	Feature value	% of variance	% of accumulated contribution rate
1	3.616	45.199	45.199	2.138	26.731	26.731
2	1.133	14.165	59.365	2.09	26.119	52.85
3	1.075	13.432	72.797	1.596	19.947	72.797

When the accumulated variance is 72.797%, 3 main factors are acquired through analysis. It can be seen from the above table that the accumulated contribution rate before and after revolving does not change, namely, the total information does not miss. It can also be seen from the above table that the accumulated contribution rate of both main factor 1 and 2 is about 26%, while that of main factor 3 is about 20%, which means that main factor 1 and 2 contribute most to heavy metal pollution in the living quarter; and main factor 3 has important function.

Factor analysis aims at placing variables with similar factor loading under the same factor; the maximum rotation of the orthogonal variance makes each main factor related to the least variables so that the load of sufficient loads is very small and meaning of factors can be explained reasonably. The output result can be seen in table 8.

Table8 The matrix of factor loading in the living quarter before and after revolving

	Before revolving			After revolving		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
As (μg/g)	0.669	-0.646	-0.010	0.300	0.868	-0.148
Cd (ng/g)	0.784	0.171	-0.417	0.849	0.224	0.216
Cr (μg/g)	0.643	0.234	0.493	0.105	0.405	0.733
Cu (μg/g)	0.729	-0.246	0.024	0.400	0.635	0.169
Hg (ng/g)	0.492	0.130	-0.437	0.666	0.066	0.048
Ni (μg/g)	0.686	-0.253	0.523	0.006	0.785	0.439
Pb (μg/g)	0.803	0.112	-0.348	0.798	0.302	0.226
Zn (μg/g)	0.501	0.691	0.267	0.277	-0.083	0.846

It can be seen in table 7 that the result of variables of loads of factors before and after revolving is basically identical. The larger the absolute value of the correlation coefficient between a variable and a factor is, the closer their relation is. It is explained in the orthogonal factor that factor 1 is the combination of Pb and Cd; factor 2 is the combination of Zn and Cr and factor 3 is the combination of As and Ni; each combination may come from a common source; and elements in three combinations are correlated at best.

In order to make analysis better, the contour line of factors distributed in the space can be drawn through the score of a single sample in the surface soil in Baiheng City on the 3 main factors after orthogonal revolving with maximum variance of 3 factors from factor analysis.
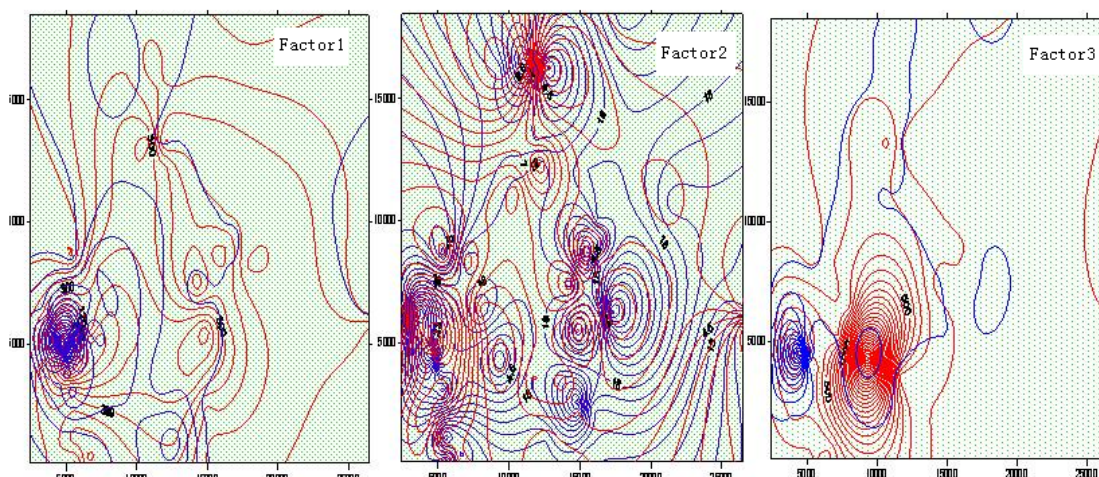
Fig-1 Distribution map of the contour line of main factors in the living quarter in the plane space

It can be seen through analyzing the distribution map of the contour line of 3 factors that sources of Pb and Cd is closely related. Main pollutants of Pb and Cd in the living quarter are from discharge of waste gas of automobiles, which spread with driving automobiles and wind power. The pollution area of Zn and Cr is large, indicating that pollution of these two metals mainly comes from additives of building materials of building in the urban areas and tyres of automobiles and waste batteries which are not processed well. As and Ni are concentrated-distributed, indicating that these two metals in the living quarter mainly come from use of pesticides and inferior chemical fertilizers in agricultural production.

Likewise, the following conclusions can be gained:

Industrial area: industrial energy sources mainly come from coal and petroleum, which are also the main sources of heavy metal pollutions such as Hg, Cr and Cd; meanwhile, discharge of three wastes in production of factories would cause lots of compounds of Cu and Pb.

Living quarter: main pollutants in the living quarter Cu, Cr and Ni mainly come from construction of roads, dust and refuse dumps on roads.

Green belt: main pollutants Pb, Cu, Zn, Ni and Cr mainly come from house refuses from residents.

Conclusion

1)Results from the evaluation and analysis of the heavy metal pollution condition in Baicheng City soil by means of fuzzy comprehensive evaluation method show that mild pollution can be examined in the living areas and the green areas of the parks; while middle level pollution can be examined in the industrial zones. On the whole, the concentration distribution of heavy metal shows certain area difference which is mainly related to the functions of the areas and generally speaking, industrial areas and commercial areas are subject to heavy pollution.

2)Results from the research and analysis of the types and source of soil heavy metal pollution in Baicheng City via factor analysis show that the major pollution factors Hg, Cr, Cd, Cu and Pb of industrial areas are mainly from coal emissions and "three wastes" discharge from factories; the major pollution factors Pb, Cu, Zn, Ni and Cr of the green areas of the parks mainly come from household garbage deserted by residents; the major pollution factors Cu, Cr and Ni of the main roads are mainly from road construction, dust emission and road landfill; the major pollution factors Pb, Cd, Zn, Cr, As and Ni of living areas mainly come from vehicle exhaust emission, usage of addition agent for building materials and tires, improper disposal of wasted batteries and usage of pesticides and chemical fertilizers.

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