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Original Research

Study and Risk Assessment of Heavy Metals and Risk Element Pollution in Shallow Soil in Shanxi Province, China

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Abstract

In order to understand the status of soil heavy metals and risk element pollution and its impact on human health, Datong area of Shanxi Province was selected as the study area. Using spss19 statistical software, the degree of soil heavy metals and risk element pollution, ecological risk and health risk were evaluated by using land accumulation index method, potential ecological hazard index method and health risk assessment model. The results showed that there were different degrees of pollution of heavy metals and risk element Pb, Cr, Zn, Cd, Ni, As, Hg and Cu in farmland soil in Datong area. The soil Pb pollution was the most serious. There were 8 light pollution points, 3 medium pollution points, 1 heavy~extremely heavy pollution point and 1 extremely heavy pollution point, accounting for 3.24%, 1.21%, 0.4% and 0.4% respectively. The distribution range of the total potential ecological index RI of heavy metals and risk element in farmland soil is 28.00~1851.01. There are slight, secondary, strong, very strong and extremely strong ecological risks, accounting for 97.57%, 1.21%, 0.4%, 0.4% and 0.4% respectively. The main risk factors are slight risks, and the influencing factors are Cd, Pb, Cu, Hg and As. Heavy metals and risk element in farmland soil have non-carcinogenic health risks for adults and children. Cr and As are the main non-carcinogenic factors in the soil of the study area; The average value of the total carcinogenic risk index is between 10^{-6} and 10^{-4}, which will not cause great harm to the health of local residents.

Keywords: shallow soil, heavy metal, risk element, ecological risk, health risk, China

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Introduction

Soil is composed of animals and plants formed by weathering of minerals and rocks, organic matter produced by decomposition of microbial residues, soil organic matter (solid matter), water (liquid matter), air (gas matter), oxidized humus, etc. In the process of industrialization, the good soil ecological environment has been continuously damaged, and the problem of soil pollution is becoming more and more serious. Heavy metal pollution in farmland soil will affect the quality of agricultural products and food safety, and endanger human health. In recent years, soil heavy metal pollution has attracted extensive attention of scholars at home and abroad. Diami et al. [1] evaluated the ecological risk and human health risk of heavy metals in the topsoil of an iron ore area in Malaysia, and found that the ecological risks of Cd, as, Pb and Cu were low, no obvious non-carcinogenic risk was found, and the potential carcinogenic risk of as was high. Obiora et al. [2] studied the pollution degree of heavy metals in cultivated soil around a zinc mining area in Southeast Nigeria, and found that the over standard rate of Pb and Zn in soil was 87% and 31%. Wang et al. [3] conducted heavy metal pollution characteristics and health risk evaluation of soil around a tungsten-molybdenum mine in Luoyang, China, and considered that the average content of heavy metals Zn, Cr, Cd and As in soil exceeded the screening value of soil pollution risk. Among heavy metals, Cd poses the greatest threat to ecology, accounting for 91.32% of RI. Soil heavy metal pollution in the study area poses a serious threat to the surrounding ecological environment and residents' health. Jing et al. [4] conducted heavy metals status, transport mechanisms, sources, and factors affecting their mobility in Chinese agricultural soils. They believe that due to the expansion of mining industry, the use of pesticides and other human activities, some soils in China are polluted by heavy metals, thus polluting the agricultural ecosystem. Alabi et al. [5] conducted effects of different land uses on soil physical and chemical properties in Odeda LGA, Ogun State, Nigeria and considered that land use types have different effects on soil properties. Sun et al. [6] conducted the ecological health risk assessment of heavy metals in the soil of Changchun new area, Jilin Province. It is considered that the average content of eight heavy metals in the soil in this area is higher than the soil background value of Changchun City, showing different degrees of accumulation. There are Hg and Cd pollution and ecological risks in the soil of Changchun new area. Because soil is the most precious natural resource, agricultural production and human survival are inseparable from healthy soil, which highlights the importance of soil heavy metal research. Although the above research has conducted in-depth research on farmland soil in different areas and in different aspects, there is no special research on Shanxi Province. I hope this research will play a positive role in food security and human health. Crops mainly grow corn, potato, millet, buckwheat, soybean, mung bean, naked oats, vegetables, etc.

Materials and Methods

Heavy metals refer to 60 elements with a density of more than 4.0 or 45 elements with a density of more than 5.0. In terms of environmental pollution, heavy metals actually refer to heavy metals with obvious biological toxicity such as mercury (Hg), cadmium (Cd), lead (Pb) and chromium (Cr), as well as general heavy metals with certain toxicity such as zinc (Zn), copper (Cu) and nickel (Ni). The heavy metal elements mainly studied in this paper include Hg, Cd, Pb, Cr, Zn, Cu and Ni. Arsenic (As) is a non-metallic, As and its compounds are used in pesticides, herbicides and insecticides. On October 27, 2017, the list of carcinogens published by the international agency for research on cancer of the World Health Organization was preliminarily sorted for reference. Arsenic and inorganic arsenic compounds were included in the list of class I carcinogens. Therefore, this paper studies as a risk element.

The survey area is located at 111°50'-114°35'E and 38°20'-40°45'N. the climate is characterized by dry and little rain, and the average temperature is about 6.5-7.5ºC. The average annual precipitation is between 363-414 mm. Sanggan River is the main river in the survey area, belonging to Haihe River system, with a maximum monthly flow of 78.8 m^3/s. It is located at the junction of Shanxi platform anticline and Yinshan uplift of North China platform. The north is Beikou uplift, the southwest is Datong jingle depression, and the southeast is Sangganhe new fault depression. A series of structural features have been formed in the multi-stage crustal tectonic changes in this area, especially the influence of Yanshan movement and Himalayan movement. Neotectonic movement is quite developed and seismicity is more frequent. The exposed strata are relatively complete, i.e. Sanggan group and Wutaishan group of Taigu, Changcheng System and Jixian system of middle and Upper Proterozoic, Cambrian, Ordovician, Carboniferous and Permian of Paleozoic, Jurassic and Cretaceous of Mesozoic and tertiary and Quaternary of Cenozoic. The soil is arid grassland chestnut soil zone.

Sample Collection and Testing

The surface soil samples were collected from the typical cultivated land or garden land in the study area. The sampling density was 1/3-4 km^2, and GPS was used for positioning. When sampling, the representative sections such as ridge, forest belt, ditch, old house foundation and roadside were avoided. The soil samples of 0~20 cm surface farmland were collected with wooden shovels. The soil was broken, and the sundries such as straw, root system and stone were picked out,

Fig.1. Location map of study area and sampling point.

and 1.0~1.5 kg was reserved and put into the sample bag for treatment after full mixing. After the soil samples were dried and crushed, they were passed through 20 mesh nylon screen, bagged and sent to the laboratory for testing. A total of 247 surface farmland soil samples were collected in the whole area, Fig. 1 shows the distribution of sampling points in the study area.

The sample test shall be carried out by the Laboratory of Harbin natural resources comprehensive survey center in accordance with the technical requirements for analysis of samples for Eco geochemical evaluation (DD 2005-03) [7], and the analysis indexes, determination methods and detection limits are shown in Table 1. The accuracy and precision are controlled by national first-class reference materials, and the qualification rate of element analysis accuracy and precision is higher than 98%. the reporting rate of element is higher than 99.6%.

Evaluation Method

Evaluation of Heavy Metals and Risk Element Pollution in Soil

The land accumulation index method proposed by German scientist Muller [8] was adopted to evaluate the degree of soil heavy metals and risk element (hereinafter referred to as heavy metals) pollution. The calculation formula is as follows:

$$I_{geo}=\log_2\left[\frac{C_i}{k\times S_i}\right] \tag{1}$$

where I_{geo} represents the geo-accumulation index of heavy metal i. C_i represents the actual measured value of heavy metal i in soil. S_i represents the reference value. k is the correction coefficient, generally 1.5. The background value of heavy metal elements in the soil of Shanxi Province (obtained from the statistics of 1:250000 land quality geochemical survey data

Table 1. Analysis method and detection limit (mg·kg^{-1}).

Index	Determination method	Detection limit	Index	Determination method	Detection limit
Hg	Atomic Fluorescence Spectrometry	0.005	As	Atomic Fluorescence Spectrometry	0.2
Pb	X ray fluorescence spectrometry	2	Cd	Plasma emission spectrometry	0.02
Cr		3	Ni		1
Zn		1	Cu		1

Table 2. I_{geo} index and the criteria of pollution grade.

Land accumulation index I_{geo}	Level	Pollution degree
I_{geo}<0	0	Pollution-free
0≤I_{geo}<1	1	Light pollution
1≤I_{geo}<2	2	Medium pollution
2≤I_{geo}<3	3	Medium to heavy pollution
3≤I_{geo}<4	4	Heavy pollution
4≤I_{geo}<5	5	Heavy to extremely heavy pollution
5≤I_{geo}	6	Extremely heavy pollution

of Shanxi Province [9]) was set as the reference value. The assessment grade of heavy metal pollution was divided according to the cumulative index of I_{geo} [10-12] (Table 2).

Ecological Risk Assessment of Heavy Metals in Soil

Hakanson's potential ecological hazard index method was used to evaluate the ecological risk of heavy metals in the soil of the study area. This method not only refers to the material content of heavy metals, but also relates to the ecological, environmental, and toxicological effects of heavy metals. It is widely used in ecological risk assessment at present [13-15]. The calculation formula is as follows:

$$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} (T_r^i \times C_f^i) = \sum_{i=1}^{n} (T_r^i \times \frac{C_i}{C_n^i}) \quad (2)$$

where C_f^i is the pollution index of a metal. C_i is the measured value of a heavy metal in soil. C_n^i is the reference value of a certain heavy metal (background value of heavy metal in Shanxi Province soil). E_r^i is the potential ecological risk index of a single heavy metal. T_r^i is the toxicity response parameter of a heavy metal. *RI* is the total potential ecological risk index. The Toxicity Coefficient of each heavy metal is as follows: Zn = 1<CR = Mn = 2<Cu = Ni = Pb = 5<As = 10<Cd = 30<Hg = 40 [14]. Single factor potential ecological hazards and total potential ecological hazards were classified according to E_r^i and *RI* (Table 3).

Human Health Risk Assessment of Heavy Metals in Soil

The health risk assessment model published by USEPA [17] was used to assess human health risks. The assessment steps included exposure calculation and risk characterization. Soil heavy metals are absorbed by humans through plants in three ways: oral direct intake, respiratory inhalation, and skin contact, which pose non-carcinogenic and carcinogenic risks to human health. These risks were characterized in this study.

(1) Exposure calculation

The daily average carcinogenic and non-carcinogenic heavy metal exposure pathways were calculated as follows:

$$ADD_{i\mathrm{ing}} = \frac{C_i \times IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (3)$$

$$ADD_{i\mathrm{nh}} = \frac{Ci \times InhR \times EF \times ED}{PEF \times BW \times AT} \quad (4)$$

$$ADD_{iderm} = \frac{C_i \times SA \times SL \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (5)$$

where $ADD_{i\mathrm{ing}}$, $ADD_{i\mathrm{inh}}$, and $ADD_{i\mathrm{derm}}$ represent the daily average exposure of a heavy metal through oral intake, respiratory intake, and skin contact, respectively, and CI represents the concentration of a heavy metal pollutant in soil. The exposed skin area was calculated according to the exposed skin area of Chinese people in different seasons and the climate characteristics of Changchun City according to Mielczarek et al. [18]. Other parameters were referred from HJ 25.3-2014 [19] and human parameters issued by the US EPA [20-21] (Table 4).

The average daily exposure of carcinogenic heavy metals in children is different from that in adults. It is necessary to calculate the exposure of children and adults separately, then weight the average, and finally allocate the exposure to the entire life cycle. The calculation formula is as follows:

$$LADD_{i\mathrm{ing}} = \frac{C_i \times EF}{AT}\left(\frac{IngR_{child} \times ED_{child}}{BW_{child}} + \frac{IngR_{adult} \times ED_{adult}}{BW_{adult}}\right) \times 10^{-6} \quad (6)$$

$$LADD_{i\mathrm{inh}} = \frac{C_i \times EF}{PEF \times AT} \times \left(\frac{InhR_{child} \times ED_{child}}{BW_{child}} + \frac{InhR_{adult} \times ED_{adult}}{BW_{adult}}\right) \quad (7)$$

$$LADD_{i\mathrm{derm}} = \frac{Ci \times EF \times SL \times ABS}{AT} \times \left(\frac{SA_{child} \times ED_{child}}{BW_{child}} + \frac{SA_{adult} \times ED_{adult}}{BW_{adult}}\right) \times 10^{-6} \quad (8)$$

(2) Risk characterization

$$HQ = \sum HQ_i = \sum \frac{ADD_{i\mathrm{ing}} + ADD_{i\mathrm{inh}} + ADD_{i\mathrm{derm}}}{RfD_i} \quad (9)$$

$$CR = \sum CR_i = \sum \left(ADD_{i\mathrm{ing}} + ADD_{i\mathrm{inh}} + ADD_{i\mathrm{derm}}\right) \times SF \quad (10)$$

In the formula, *HQ* refers to the non-carcinogenic risk index of all heavy metals. HQ_i refers to the non-carcinogenic risk index of a single heavy metal I. RfD_i refers to the non-carcinogenic daily average intake of heavy metal i. *HQ* or HQ_i<1 indicates that

Table 3. Indices used to assess the potential ecological risk status.

Ecological hazards	Slight	Medium	Strong	Very strong	Extremely strong
Potential ecological hazard index of single heavy metal E_r^i	<40	40–80	80–160	160–320	≥320
Total potential ecological hazard index *RI*	<150	150–300	300–600	600–1200	≥1200

Table 4. Health risk exposure parameters of heavy metals.

Symbol	Parameter	Unit	Adult reference value	Child reference value
ED	Exposure years	a	25	6
BW	Average weight	kg	56.8	15.9
EF	Exposure frequency	$d\cdot a^{-1}$	350	350
AT	Average exposure time	d	carcinogenic26280, Non-carcinogenic9125	carcinogenic26280, Non-carcinogenic2190
IngR	Daily soil intake	$mg\cdot d^{-1}$	100	200
InhR	Daily air respiration	$m^3\cdot d^{-1}$	14.5	7.5
SA	Exposed skin surface area	cm^2	2415	1295
SL	Skin adhesion coefficient	$mg\ (cm^2\cdot d)^{-1}$	0.2	0.2
PEF	Surface dust emission factor	$m^3\cdot kg^{-1}$	1.36×10^9	1.36×10^9
ABS	Skin absorption factor		0.001	0.001

the non-carcinogenic risk can be ignored, otherwise, the non-carcinogenic risk cannot be ignored. *CR* refers to the carcinogenic health risk index of all heavy metals, CR_i refers to the carcinogenic risk index of single heavy metal I, and SF refers to the carcinogenic slope factor. The *RfD* and *SF* values of different exposure routes are shown in Table 5. According to some studies, the acceptable range of the carcinogenic health risk index *CR* or CR_i is 10^{-6}–10^{-4} [22-24].

Results and Discussions

Distribution Characteristics of Heavy Metals in Soil

The content of heavy metals in the soil of the study area (Table 6) is higher than the soil background value of Shanxi Province, indicating that some heavy metals accumulate in the soil to a certain extent. The order of content is Cr>Zn>Cu>Ni>Pb>As>Cd>Hg, the Cr content is 32.45 ~ 354.3 mg/kg, and the average value is 86.76 mg/kg. Zn content is 24.99~713.3 mg/kg, with an average of 28.35 mg/kg. The content of Cu is 7.52~1884 mg/kg, with an average of 29.33 mg/kg. The content of Ni is 8.09~130.7 mg/kg, with an average of 24.92 mg/kg. Pb content is 4.88~1108.18 mg/kg, with an average of 24.92 mg/kg. The content of As is 0.6~62.67 mg/kg, with an average of 9.19 mg/kg. The content of Cd is 0.04~4.84 mg/kg, with an average of 0.15 mg/kg. The content of Hg is 0~1.25 mg/kg, with an average of 0.03 mg/kg. From the coefficient of variation, Cu is significantly higher than other elements, reaching 4.21. The coefficients of variation of Pb, Hg and Cd were also high, which were 2.99, 2.67 and 2.27 respectively. The coefficient of variation of other elements ranged from 0.3 to 0.76. The larger the coefficient of variation, the more uneven the distribution of elements in soil.

Table 5. Heavy metal reference measurement and carcinogenic slope factor.

Heavy metal	Reference measurement RfD ($mg\cdot kg^{-1}\cdot d^{-1}$)			Carcinogen SF ($kg\cdot d\cdot mg^{-1}$)		
	Through mouth	Skin	Breathing	Through mouth	Skin	Breathing
As	3.0×10^{-4}	3.0×10^{-4}	1.5×10^{-5}	1.5	1.5	4.3×10^{-3}
Cd	1.0×10^{-3}	2.5×10^{-5}	1.0×10^{-5}	6.1	6.1	6.3
Cr	3.0×10^{-3}	7.5×10^{-5}	2.55×10^{-5}	—	—	42
Cu	4.0×10^{-2}	4.0×10^{-2}	—	—	—	—
Hg	3.0×10^{-4}	2.1×10^{-5}	3.0×10^{-4}	—	—	—
Ni	2.0×10^{-2}	8.0×10^{-4}	2.3×10^{-5}	—	—	0.84
Pb	3.5×10^{-3}	5.3×10^{-4}	3.5×10^{-3}	—	—	—
Zn	3.0×10^{-1}	3.0×10^{-1}	—	—	—	—

Table 6. Concentrations distribution of heavy metals in the study area.

Characteristic parameter	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Maximum value	62.67	4.84	354.3	1884	1.25	130.7	1108.18	713.3
Minimum value	0.6	0.04	32.45	7.52	0	8.09	4.88	24.99
Average value	9.19	0.15	86.76	29.33	0.03	28.35	24.92	61.22
Standard deviation	4.54	0.34	26.06	123.4	0.08	10.91	74.47	46.58
Coefficient of variation	0.49	2.27	0.3	4.21	2.67	0.38	2.99	0.76
Soil background value	9.8	0.128	61.8	26.9	0.27	32	15.8	75.5

Note: the background value of soil heavy metals in Shanxi Province is obtained from the statistics of land quality geochemical survey data [9], and the coefficient of variation is dimensionless.

Correlation Analysis of Heavy Metals in Soil

The correlation of heavy metals in soil can be used to infer whether heavy metals are homologous. If the correlation is large, it indicates that the sources of heavy metals may be the same. If the correlation is small, it indicates that their sources may be different. Spss19 software was used to analyze 8 kinds of heavy metals in the soil of the study area by Pearson method. The results are shown in Table 7.

According to the correlation coefficient in Table 7, Pb, Zn, Cu, Cd, Hg and As in the soil heavy metal elements in the study area are significant ($P<0.01$), and the correlation coefficient values are greater than 0.5, up to 0.967, indicating that there is a very close positive correlation between Pb and Zn, Cu, Cd, Hg and As, and between Cr and Ni ($P<0.01$), And the correlation coefficient is 0.733, indicating that there is a very close positive correlation between Cr and Ni. From the above results, Pb, Zn, Cu, Cd, Hg and As may have the same source, and Cr and Ni may have the same source.

Analysis of Soil Heavy Metal Pollution Degree

Taking the soil background value of Shanxi Province as the evaluation standard, the geoaccumulation index of soil heavy metal pollution degree in the study area is evaluated (Table 8). The average value of heavy metal pollution index from high to low is Pb>Cu>Cd >Zn> As>Cr>Ni>Hg. Soil Pb pollution is the most serious. There are 8 light pollution points, 3 medium pollution points, 1 heavy~extremely heavy pollution point and 1 extremely heavy pollution point, accounting for 3.24%, 1.21%, 0.4% and 0.4% respectively. Cu takes the second place, there are 4 light pollution points, 1 medium~heavy pollution point, 1 heavy pollution point and 1 very heavy pollution point, accounting for 1.61%, 0.4%, 0.4% and 0.4% respectively. There are 5 light pollution points, 2 medium pollution points, 2 medium~heavy pollution points, 1 heavy pollution point and 1 heavy~extremely heavy pollution point in Cr, accounting for 2.02%, 0.8%, 0.8%, 0.4% and 0.4% respectively. There are 5 light pollution points, 1 medium pollution point and 1 medium~heavy pollution point in Zn, accounting for 2.02%, 0.8%, 0.8%, 0.4%, 0.4% and 5 light pollution points and 1 medium~heavy pollution point in As, accounting for 2.02% and 0.4% respectively. There are 60 slight pollution points and 2 medium pollution points in Cr, accounting for 24.29% and 0.8% respectively. There are 8 slight pollution points and 1 medium pollution point in Ni, accounting for 3.24% and 0.4% respectively. There is one medium

Table 7. Correlation of heavy metals in topsoil of the study area.

	Pb	Zn	Cr	Cd	Ni	As	Hg	Cu
Pb	1							
Zn	.941**	1						
Cr	0.039	.172**	1					
Cd	.967**	.942**	0.07	1				
Ni	0.041	.213**	.733**	0.082	1			
As	.784**	.693**	-.140*	.754**	-0.047	1		
Hg	.920**	.889**	0.037	.882**	0.047	.762**	1	
Cu	.584**	.497**	-0.001	.550**	0.061	.386**	.296**	1

**. It was significantly correlated at the level of 0.01.
*. There was significant correlation at the level of 0.05.

Table 8. The classification of heavy metals in soil based on the $I_{geo.}$

Heavy metal	Index mean	Number of samples at all levels						
		Pollution-free	Light pollution	Medium pollution	Medium to heavy pollution	Heavy pollution	Heavy to extremely heavy pollution	Extremely heavy pollution
Pb	-0.35	234	8	3	0	0	1	1
Zn	-0.99	240	5	1	1	0	0	0
Cr	-0.14	185	60	2	0	0	0	0
Cd	-0.83	236	5	2	2	1	1	0
Ni	-0.83	238	8	1	0	0	0	0
As	-0.82	241	5	0	1	0	0	0
Hg	-4.31	246	0	1	0	0	0	0
Cu	-1.11	240	4	0	1	1	0	1

pollution point in Hg, accounting for 0.4%. However, the mean value of the ground accumulation index of Pb, Cr, Zn, Cd, Ni, As, Hg and Cu is less than 0, which is generally in a pollution-free state. However, there are heavy to extremely heavy pollution points in Pb and extremely heavy pollution points in Cu, which need to be paid enough attention.

Potential Ecological Risk Assessment of Heavy Metals

Taking the soil background value of Shanxi Province as the reference ratio, the risk degree of soil potential ecological hazards in the study area is evaluated (Table 9). From the perspective of potential ecological risks of individual heavy metals, the Cd risk index ranges from 10.04 to 1133.44, with slight to extremely strong ecological risks, with extremely strong risk points accounting for 1.21%, very strong risk points accounting for 0.4%, strong risk points accounting for 0.4%, medium risk points accounting for 4.85% and slight risk points accounting for 92.71%, mainly minor risks. The range of Pb and Cu risk indexes is 1.54~305.69 and 1.40~350.19 respectively. There are extremely strong and strong risk points, accounting for 0.4% respectively. Hg risk index ranges from 0.52 to 185.58, with strong ecological risk, accounting for 0.4%. As risk index ranges from 0.61 to 63.95, with medium ecological risk, accounting for 0.4%. Therefore, Cd, Cu and Pb are the main ecological hazard elements in the soil of the study area, followed by Hg and As, and other elements are at a slight level. The ecological risk indexes of Cr, Ni and Zn of all samples are less than 40, which is a slight ecological risk.

The total potential ecological index RI of heavy metals in the study area ranges from 28.00 to 1851.01, with slight, medium, strong, very strong and extremely strong ecological risks, mainly slight and medium, accounting for 97.57%, 1.21%, 0.4%, 0.4% and 0.4% respectively. The influencing factors are Cd, Pb, Cu, Hg and As. The ecological risk of Cd has five grades: slight, medium, strong, very strong and extremely strong.

Table 9. Potential ecological risk coefficient for every heavy metal in soil.

Hazard index		Distribution range	Number of samples at all levels				
			Slight	Medium	Strong	Very strong	Extremely strong
Ei	Cd	10.04~1133.44	229	12	2	1	3
	Hg	0.52~185.58	246	0	0	1	0
	Cr	1.05~11.47	247	0	0	0	0
	As	0.61~63.95	246	1	0	0	0
	Ni	1.26~20.42	247	0	0	0	0
	Pb	1.54~305.69	245	0	1	0	1
	Zn	0.33~9.45	247	0	0	0	0
	Cu	1.40~350.19	245	0	1	0	1
RI		28.00~1851.01	241	3	1	1	1

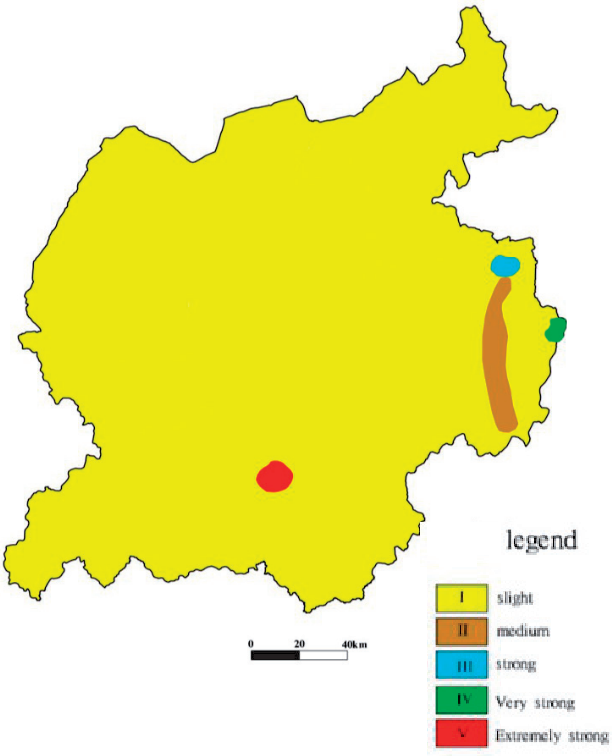

Fig. 2. The spatial distribution of total potential ecological grade.

The ecological risks of Pb and Cu are slight, strong and extremely strong. Hg has two grades: slight and very strong. As has two grades: slight and medium. Other heavy metals have slight ecological risks. The spatial distribution map of RI (Fig. 2) shows that Tanshang town has the highest ecological risk, and the soil in some areas has extremely strong ecological risk. It is found that there are mining mines integrating mining, ore washing and transportation in the area, and there are coal, iron ore, magnesium smelting dolomite and other mining areas in Lingqiu County and Guangling county. Affected by it, there are very strong, strong and medium ecological risk levels in the East, other areas are far away from the mining area, with low ecological risk and slight intensity.

Human Health Risk Assessment

Heavy Metal Exposure Assessment Analysis

Firstly, the daily exposure of soil heavy metals in the study area was evaluated (Table 10 and Table 11). In the average daily non-carcinogenic exposure, the order of average daily intake of adults and children from high to low is ADD_{ing}>ADD_{derm}>ADD_{inh} The amount of heavy metals ingested by mouth is much higher than that inhaled through skin contact and respiration. The order of average daily intake of different heavy metals from high to low is Cr>Zn>Cu>Ni>Pb>As>Cd>Hg. The daily intake and total daily intake of all heavy metals in children are higher than those in adults. Among the average daily carcinogenic exposure of As, Cd, Cr and Ni, oral intake is also much higher than skin and respiration. The order of average daily intake from high to low is Cr>Ni>As>Cd, and the intake of children is higher than that of adults. Therefore, in the assessment of carcinogenic and non-carcinogenic exposure to heavy metals in soil, oral intake is the main exposure route, and the average daily exposure of children is higher than that of adults.

Health Risk Assessment

According to the health risk assessment model, assessment parameters and survey data, the non-carcinogenic health risk assessment indexes of 8 heavy metals and carcinogenic health risk assessment indexes of 4 heavy metals in the study area are calculated (Table 12 and Table 13).

In the non-carcinogenic health risk assessment, the non-carcinogenic risks of the same element in different exposure routes of adults and children are HQing>HQderm>HQinh, which is consistent with the exposure assessment conclusion, indicating that the non-carcinogenic risk is related to the exposure route, and oral intake is the main way of non-carcinogenic risk of soil heavy metals. From high to low, the non-carcinogenic risk of different heavy metals is Cr>As>Pb>Ni>Cu>Cd>Hg in adults and As>Cr>Pb>Ni>Cu>Zn>Cd>Hg in children. The average value of single non-carcinogenic risk index of heavy metals is less than 1, indicating that there is no non-carcinogenic risk of single heavy metals to human health. The single risk index of heavy metals in children is higher than that in adults, and they are more likely to be harmed. The average value of the total adult non-carcinogenic health risk index is 0.128 and the maximum value is 1.26, indicating that these eight heavy metals in the soil of the study area have non-carcinogenic health risks for adults. The average value of the total health risk index of heavy metals in children is 0.857 and the maximum value is 8.67, indicating that heavy metals in soil in this area have non-carcinogenic health risks for children, which is greater than that for adults. From the composition proportion of the average value of the total non-carcinogenic risk index (Fig. 3), Cr and As are the main non-carcinogenic factors in the soil of the study area. As has a great non-carcinogenic health threat to children, so the risk prevention and control of this element should be strengthened.

In the health risk assessment of carcinogenesis, the carcinogenic risk of adults and children exposed to the same element in different ways is also CRing >CRderm>CRinh, and the carcinogenic risk is also closely related to the exposure route. The carcinogenic risk of heavy metals from high to low is As>Cd> Cr>Ni, indicating that As has the highest carcinogenic risk. The average values of the total cancer risk index

Table 10. Non-carcinogenic average daily exposure doses of heavy metals in soil.

Heavy metal		Adult				Children			
		ADD_{ing}	ADD_{inh}	ADD_{derm}	ADD	ADD_{ing}	ADD_{inh}	ADD_{derm}	ADD
Pb	Max	1.87E-03	1.99E-07	9.04E-06	1.88E-03	1.34E-02	3.69E-07	1.73E-05	1.34E-02
	Avg	4.21E-05	4.49E-09	2.03E-07	4.23E-05	3.01E-04	8.29E-09	3.88E-07	3.01E-04
Zn	Max	1.20E-03	1.28E-07	5.82E-06	1.21E-03	8.60E-03	2.37E-07	1.11E-05	8.61E-03
	Avg	1.03E-04	1.10E-08	4.92E-07	1.04E-04	7.38E-04	2.04E-08	9.43E-07	7.39E-04
Cr	Max	5.98E-04	6.38E-08	2.89E-06	6.01E-04	4.27E-03	1.18E-07	5.53E-06	4.28E-03
	Avg	1.46E-04	1.56E-08	6.98E-07	1.47E-04	1.05E-03	2.89E-08	1.34E-06	1.05E-03
Cd	Max	8.16E-06	8.70E-10	3.94E-08	8.20E-06	5.83E-05	1.61E-09	7.55E-08	5.84E-05
	Avg	2.45E-07	2.61E-11	1.16E-09	2.46E-07	1.75E-06	4.83E-11	2.22E-09	1.75E-06
Ni	Max	2.21E-04	2.35E-08	1.07E-06	2.22E-04	1.58E-03	4.35E-08	2.04E-06	1.58E-03
	Avg	4.79E-05	5.10E-09	2.28E-07	4.81E-05	3.42E-04	9.43E-09	4.36E-07	3.42E-04
As	Max	1.06E-04	1.13E-08	5.11E-07	1.06E-04	7.56E-04	2.08E-08	9.79E-07	7.57E-04
	Avg	1.55E-05	1.65E-09	7.45E-08	1.56E-05	1.11E-04	3.06E-09	1.43E-07	1.11E-04
Hg	Max	2.11E-06	2.25E-10	1.02E-08	2.13E-06	1.51E-05	4.17E-10	1.96E-08	1.51E-05
	Avg	4.92E-08	5.24E-12	2.36E-10	4.94E-08	3.51E-07	9.69E-12	4.52E-10	3.52E-07
Cu	Max	3.18E-03	3.39E-07	1.54E-05	3.20E-03	2.27E-02	6.27E-07	2.94E-05	2.28E-02
	Avg	4.95E-05	5.28E-09	2.37E-07	4.98E-05	3.54E-04	9.75E-09	4.54E-07	3.54E-04
ADD	Max	7.19E-03	7.67E-07	3.47E-05	7.23E-03	5.14E-02	1.42E-06	5.63E-03	5.70E-02
	Avg	4.05E-04	4.32E-08	1.93E-06	4.07E-04	2.89E-03	7.98E-08	1.48E-04	3.04E-03

Note: "max " represents the maximum value and "avg " represents the average value, the same below.

for adults and children were 8.87 respectively × 10^{-6} and 2.37 × 10^{-5}, the maximum values are 7.37 respectively × 10^{-5} and 1.98 × 10^{-4}, all in the range of 10^{-6}~10^{-4}. It is considered that the carcinogenic risk caused by soil heavy metals in Shanxi Province is generally acceptable and will not cause great harm to the health of local residents, but they all exceed the soil treatment benchmark value 10^{-6} proposed by the U.S. EPA, and prevention should be strengthened.

Table 11. Carcinogenic average daily exposure doses of As, Cd, Cr and Ni in soil (mg/(kg/d)).

Heavy metal		Adult				Children			
		ADD_{ing}	ADD_{inh}	ADD_{derm}	ADD	ADD_{ing}	ADD_{inh}	ADD_{derm}	ADD
Cr	Max	2.08E-04	2.21E-08	1.00E-06	2.09E-04	5.64E-04	3.20E-08	1.46E-06	5.65E-04
	Avg	5.09E-05	5.42E-09	2.42E-07	5.11E-05	1.38E-04	7.83E-09	3.59E-07	1.38E-04
Cd	Max	2.83E-06	3.02E-10	1.37E-08	2.85E-06	7.70E-06	4.36E-10	2.00E-08	7.72E-06
	Avg	8.52E-08	9.08E-12	4.03E-10	8.56E-08	2.31E-07	1.31E-11	6.00E-10	2.32E-07
Ni	Max	7.66E-05	8.17E-09	3.70E-07	7.70E-05	2.08E-04	1.18E-08	5.40E-07	2.09E-04
	Avg	1.66E-05	1.77E-09	7.91E-08	1.67E-05	4.51E-05	2.56E-09	1.17E-07	4.52E-05
As	Max	3.67E-05	3.92E-09	1.77E-07	3.69E-05	9.97E-05	5.65E-09	2.59E-07	1.00E-04
	Avg	5.39E-06	5.75E-10	2.59E-08	5.42E-06	1.46E-05	8.29E-10	3.80E-08	1.47E-05
ADD	Max	3.24E-04	3.45E-08	1.56E-06	3.25E-04	8.79E-04	4.98E-08	2.28E-06	8.82E-04
	Avg	7.30E-05	7.78E-09	3.48E-07	7.33E-05	1.98E-04	1.12E-08	5.14E-07	1.99E-04

Table 12. Non-carcinogenic health risk index of heavy metals in soil.

Heavy metal		Adult				Children			
		HQ	HQ_{ing}	HQ_{inh}	HQ_{derm}	HQ	HQ_{ing}	HQ_{inh}	HQ_{derm}
Pb	Max	5.52E-01	5.35E-01	5.70E-05	1.70E-02	3.85E+00	3.82E+00	1.05E-04	3.27E-02
	Avg	1.24E-02	1.20E-02	1.28E-06	3.82E-04	8.66E-02	8.59E-02	2.37E-06	7.33E-04
Zn	Max	4.03E-03	4.01E-03		1.94E-05	2.87E-02	2.87E-02		3.71E-05
	Avg	3.46E-04	3.44E-04		1.64E-06	2.46E-03	2.46E-03		3.14E-06
Cr	Max	2.40E-01	1.99E-01	2.50E-03	3.85E-02	1.50E+00	1.42E+00	4.62E-03	7.38E-02
	Avg	5.87E-02	4.88E-02	6.12E-04	9.31E-03	3.68E-01	3.49E-01	1.13E-03	1.78E-02
Cd	Max	9.83E-03	8.16E-03	8.70E-05	1.58E-03	6.15E-02	5.83E-02	1.61E-04	3.02E-03
	Avg	2.94E-04	2.45E-04	2.61E-06	4.64E-05	1.85E-03	1.75E-03	4.83E-06	8.89E-05
Ni	Max	1.34E-02	1.10E-02	1.02E-03	1.33E-03	8.33E-02	7.88E-02	1.89E-03	2.55E-03
	Avg	2.90E-03	2.39E-03	2.22E-04	2.85E-04	1.81E-02	1.71E-02	4.10E-04	5.45E-04
As	Max	3.55E-01	3.53E-01	7.52E-04	1.70E-03	2.52E+00	2.52E+00	1.39E-03	3.26E-03
	Avg	5.21E-02	5.17E-02	1.10E-04	2.48E-04	3.70E-01	3.70E-01	2.04E-04	4.76E-04
Hg	Max	7.54E-03	7.05E-03	7.52E-07	4.86E-04	5.13E-02	5.04E-02	1.39E-06	9.32E-04
	Avg	1.75E-04	1.64E-04	1.75E-08	1.12E-05	1.07E-03	1.04E-03	2.86E-08	2.66E-05
Cu	Max	7.99E-02	7.95E-02		3.84E-04	5.69E-01	5.68E-01		7.36E-04
	Avg	1.24E-03	1.24E-03		5.92E-06	8.86E-03	8.84E-03		1.13E-05
HQ	Max	1.26E+00	1.20E+00	4.42E-03	6.11E-02	8.67E+00	8.55E+00	8.17E-03	1.17E-01
	Avg	1.28E-01	1.17E-01	9.49E-04	1.03E-02	8.57E-01	8.36E-01	1.75E-03	1.97E-02

Discussion

Heavy metals are more prominent in soil inorganic pollutants. It is found that the heavy metals Pb, Cr, Zn, Cd, Ni, As, Hg and Cu in farmland soil of Shanxi Province are polluted to varying degrees, especially the heavy~extremely heavy pollution points in Pb and the extremely heavy pollution points in Cu, which need to be paid enough attention. Fortunately, the average cumulative index of the eight heavy metals is less than 0, which is in a pollution-free state as a whole. Yao et al. [25] in the soil heavy metal pollution characteristics and ecological risk assessment of Shanxi Province, Ge et al. [26] in the potential ecological risk

Table 13. Carcinogenic health risk index of heavy metals (Cr,Cd,Ni,As) in soil.

Heavy metal		Adult				Children			
		CR	CR_{ing}	CR_{inh}	CR_{derm}	CR	CR_{ing}	CR_{inh}	CR_{derm}
Cr	Max	9.30E-07		9.30E-07		1.34E-06		1.34E-06	
	Avg	2.28E-07		2.28E-07		3.29E-07		3.29E-07	
Cd	Max	1.74E-05		1.90E-09		4.71E-05		2.75E-09	
	Avg	5.22E-07		5.72E-11		1.41E-06		8.26E-11	
Ni	Max	6.86E-09		6.86E-09		9.90E-09		9.90E-09	
	Avg	1.49E-09		1.49E-09		2.15E-09		2.15E-09	
As	Max	5.54E-05	5.51E-05	1.68E-11	2.66E-07	1.50E-04	1.50E-04	2.43E-11	3.89E-07
	Avg	8.12E-06	8.08E-06	2.47E-12	3.88E-08	2.20E-05	2.19E-05	3.57E-12	5.70E-08
CR	Max	7.37E-05	5.51E-05	9.39E-07	2.66E-07	1.98E-04	1.50E-04	1.36E-06	3.89E-07
	Avg	8.87E-06	8.08E-06	2.29E-07	3.88E-08	2.37E-05	2.19E-05	3.31E-07	5.70E-08

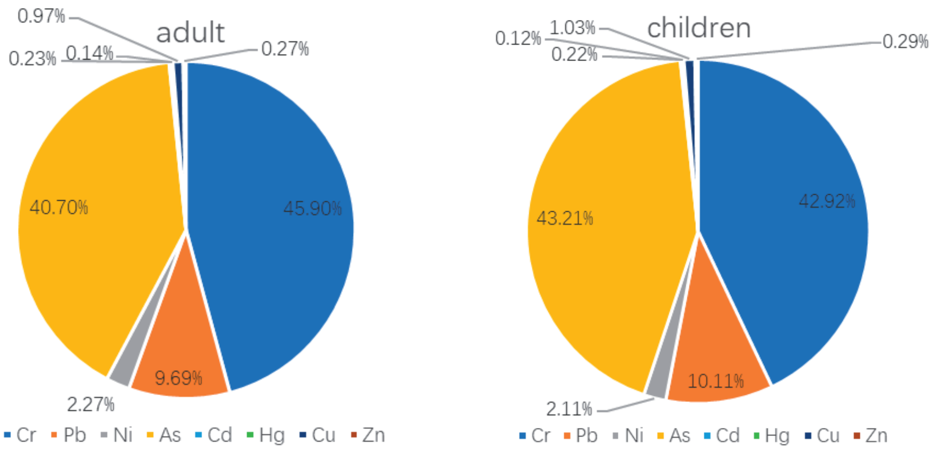

Fig. 3. Adults and children HQ contribution rate of 8 heavy metals in the soil.

assessment of soil heavy metals in typical industrial development areas of Shanxi Province, they all believe that the contents of 8 kinds of heavy metals exceed the background value of soil surface in Shanxi Province, indicating that there is soil heavy metal pollution in Shanxi Province.

Ecological risk is the possibility of system function loss caused by the change of ecosystem composition and structure caused by natural change of environment or human activities. The potential ecological risk assessment results of heavy metals show that the distribution range of the total potential ecological index RI of heavy metals in the study area is 28.00~1851.01, with slight, medium, strong, very strong and extremely strong ecological risks, accounting for 97.57%, 1.21%, 0.4%, 0.4% and 0.4% respectively, mainly slight and medium. The influencing factors are Cd, Pb, Cu, Hg and As. Han et al. [27] in the assessment of soil heavy metal pollution and potential ecological risk in conventional agricultural villages - Shouyang County, Shanxi Province as an example, from the perspective of comprehensive potential ecological risk index, the average RI of 8 kinds of heavy metals in all sample points is 151.47, belonging to medium ecological risk level, in which Hg and Cd are the main contributing factors, and the ecological risk of other heavy metals is very low. Ge et al. [26] in the potential ecological risk assessment of soil heavy metals in typical industrial development areas of Shanxi, they all believe that the local farmland soils Cr, Ni, Pb, As, Cu and Zn have slight ecological risks, and Cd and Hg have large ecological risks. Yao et al. [28] in the soil heavy metal pollution characteristics and ecological risk assessment of Shanxi Province, they believe that the range of RI of 8 kinds of heavy metals is 147.85~19649.40, with an average value of 409.71, which has serious ecological risk. Among the eight potential ecological risk factors of heavy metals, Cd is at the severe risk level and Hg is at the moderate risk level. The above scholars are consistent with the research results of this paper. Everyone believes that there are ecological risks of soil heavy metals, and the main influencing factors are Cd and Hg.

Health risk refers to the possible development of disease, disability and health loss due to the influence of natural, social and human factors in the process of human life. These eight heavy metals in the soil of the study area have non-carcinogenic health risks for adults and children. Cr and As are the main non-carcinogenic factors in the soil of the study area. As has a great non-carcinogenic health threat to children, in the order of As>Cr>Pb>Ni>Cu>Zn>Cd>Hg. The carcinogenic risk caused by soil heavy metals in Shanxi Province is generally acceptable and will not cause great harm to the health of local residents. Zhao et al. [29] in the assessment of heavy metal compound pollution and health risk of farmland soil crop system in sewage irrigation area of Shanxi Province, it is considered that eating rhizome vegetables has potential health risk for adults from the perspective of health risk index. For children, except cereals, the other four crops have potential health risks to children, and the health risk of heavy metals ingested through local crop products to adults is slightly higher than that to children. It shows that soil heavy metals have an impact on human health through crops, and soil heavy metals have health risks. In the health risk assessment of heavy metals in some farmland soils in industrial and mining areas of Jincheng City, Shanxi Province, Yang et al. [30] believe that the health risk index of eight heavy metals is at the level of 10^{-3}-1. Except arsenic, the other seven elements will not harm the health of local residents and do not reach the chronic reference amount (USEPA). The results of total health risk assessment showed that the total health risk index of eight heavy metals exceeded 1, and the non-carcinogenic health risk coefficient of heavy metals was as >Ni>Cr>Cd>Pb>Hg>Cu>Zn. Yang's research is consistent with this study in two aspects: one is that there are health risks in soil heavy metals, and the other is that As is the main element affecting health.

Conclusion

(1) The distribution of heavy metals in farmland soil in Shanxi Province is uneven, Cu is the most obvious, Pb, Hg and Cd are the second, and the variability of Cr, Zn, Ni and As is medium.

(2) He heavy metals Pb, Cr, Zn, Cd, Ni, As, Hg and Cu in farmland soil of Shanxi Province are polluted to varying degrees. The soil Pb pollution is the most serious. There are 8 light pollution points, 3 medium pollution points, 1 heavy~extremely heavy pollution point and 1 extremely heavy pollution point, accounting for 3.24%, 1.21%, 0.4% and 0.4% respectively. Cu followed.

(3) The distribution range of the total potential ecological index RI of heavy metals in farmland soil in Shanxi Province is 28.00~1851.01. There are slight, medium, strong, strong and very strong ecological risks, accounting for 97.57%, 1.21%, 0.4%, 0.4% and 0.4% respectively, mainly slight and medium. The influencing factors are Cd, Pb, Cu, Hg and As.

(4) Eight heavy metals in farmland soil in Shanxi Province have non-carcinogenic health risks for adults and children. Cr and As are the main non-carcinogenic factors in the soil of the study area. The average value of the total carcinogenic risk index is between 10^{-6} and 10^{-4}, which will not cause great harm to the health of local residents.

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Conflicts of Interest

There is no conflict of interest in the article.

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